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## **West Kootenay Climate Vulnerability and Resilience Project**

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### **Report #1:**

### **Vulnerability, Resilience and Climate Change: Adaptation Potential for Ecosystems and Their Management in the West Kootenay – Summary Report**

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**A Project Funded by the British Columbia Future Forest Ecosystem Council**

Citation: Holt, R.F., G. Utzig, H. Pinnell and C. Pearce. 2012. Vulnerability, Resilience and Climate Change: Adaptation Potential for Ecosystems and Their Management in the West Kootenay – Summary Report. Report #1 for the West Kootenay Climate Vulnerability and Resilience Project. Available at [www.kootenayresilience.org](http://www.kootenayresilience.org)

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## Acknowledgements

Many people participated in and collaborated with us on this project. The ongoing project team – Rachel Holt, Greg Utzig, Heather Pinnell, Cindy Pearce would like to thank the following: Pam Dykstra for her work early on the project; Mike Stolte for his work on the first survey; the UBC “Innes Team” – particularly Howie Harshaw who worked with us collaboratively throughout the project; FFESC for the funding opportunity and support to initiate this work in the West Kootenays – and their patience with our endless delays; and three anonymous reviewers who provided useful input to the final reports. Many thanks to the local and provincial science and technical input – in particular: Brad Hawkes, Ken Lertzman, Deb Mackillop, Trevor Murdock, Michael Murray and Art Stock. A very special thanks to David Roberts and Laura Gray from the University of Alberta for supplying the bioclimate data and useful information on how to interpret it. We also benefited along the way from ongoing discussions with Dave Daust, Don Morgan, Ken Zielke, and Harry Nelson.

Finally, we heartfully thank the large number of local forest management participants – there are too many to name – but in particular we would like to thank those people who took the plunge and attended the various project workshops.

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## EXECUTIVE SUMMARY

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### **Introduction**

Recent reports by the International Panel on Climate Change (IPCC) confirm that global climate change is underway, and likely to accelerate over the coming decades unless humans make drastic cuts to global greenhouse gas (GHG) emissions. In British Columbia, analysis of historical climate data confirms that parallel climatic changes are also occurring in this province. Apparent visible evidence of changes in climate are also becoming increasingly apparent to local people in the West Kootenays – witnessed through a wide range of changes in broad variety of indicators.

The British Columbia government has recognized that the uncertainties associated with climate change demand a new approach to forest management. With the establishment of the Future Forest Ecosystems Initiative (FFEI) in 2006, the province began a move toward looking for ways to adapt the forest and range management framework with respect to potential future climates. The province established the Future Forest Ecosystem Scientific Council (FFESC) in 2008 to deliver research grants to support the objectives of the FFEI. This report is a Summary of the findings of various components of one project that was among those funded by the FFESC under their 2009 call for proposals. **Ten additional reports are available with details on each aspect of the project.**

The project has three integrated objectives:

- to undertake an ecological vulnerability assessment using local climate predictions for the West Kootenays, under three recommended climate change scenarios for this region;
- to work with local forest practitioners, and science experts to collaboratively learn about the range of climate futures and their potential implications for the West Kootenay ecosystems; and,
- to case study the application of concepts within this field – in particular, vulnerability assessment, resilience, risk management and structured decision-making, with emphasis on the first two.

The study area is located in southeastern British Columbia, composed of the Columbia Valley River valley between Beaton Arm and the US border, and the Slocan, Kootenay, Lardeau and Duncan valleys. There are numerous small communities scattered throughout the study area, including Nakusp and Trout Lake in the north, Castlegar, Rossland and Trail in the southwest, Creston and Yahk in the southeast, and Kaslo, Nelson and New Denver in the center.

Traditionally in BC the logical unit for an ecological assessment would be a Biogeoclimatic Classification unit or an Ecosection. However, because both of those classification systems are based on an assumption of a relatively stable climate and species distribution, neither system will adequately portray the range of niches and biological diversity of the province as the impacts of climate change proceed over the coming decades. To fill this classification void, we developed an alternative system for identifying broad ecosystems, based on enduring features. We used a combination of topographic breaks and uniform elevational sequences of currently mapped biogeoclimatic units to define geographic areas with relatively similar regional climates which we term “Regional Landscapes” (RL). Because macro topography is stable in the face of climate change, we hypothesize that the climate of individual RLs will likely remain relatively homogeneous even as climate change proceeds.

### **Projected Changes in Seasonal Climate**

To explore the range of climate projections for the study area, nine climate scenarios were selected for preliminary investigation. The selection included seven General Circulation Models (GCMs) and three greenhouse gas (GHG) emission scenarios, representing a cross-section of projected changes in annual temperature and precipitation.

Based on a comparison of model output and recorded climate data, all of the models were reasonably capable of simulating seasonal patterns of temperature for the study area during the baseline period (1961-90), although on average, they tend to slightly under-estimate temperatures in all seasons except summer. The seasonal pattern of spring, summer and fall precipitation for the reference period was also reasonably well simulated by most of the GCMs, although slightly under-estimated on an absolute basis. Winter precipitation however, was significantly under-estimated by all of the GCMs. This is likely mainly due to the resolution of the global climate models, and their inability to fully capture the effects of topography on precipitation. These results provide us with some evidence that most of the models tested are potentially useful for projecting future temperatures and precipitation for the study area, with some concern for winter values.

Future projections for the study area estimate that by the 2080s, winter, spring and fall will be warmer by 2 to 5°C, and summer will be warmer by 3 to 7°C. Precipitation is projected to increase by 10-25% in the winter, spring and fall, and in the summer either remain unchanged, or decrease by up to 30%. The most obvious trend shown by the models is an increase in summer moisture stress. The other major conclusion was that variability between GCMs exceeded variation due to emission scenarios, indicating that there is still significant uncertainty in our understanding of how the global climate system operates, and specifically how it will respond to increasing GHG concentrations.

## Bioclimate Envelope Modeling

Three climate scenarios that generally illustrate the range of climate projections for BC were selected for ecosystem bioclimate envelope modeling using RandomForest and PRISM-based climate data. The three scenarios include combinations of three GCMs and GHG emission scenarios: a “**Warm/Moist**” scenario with low emissions (HadCM3\_B1), a “**Hot/Wet**” scenario with high emissions (CGCM3\_A2 ), and “**Very Hot/Dry**” scenario with moderate emissions (HadGEM\_A1B). We use the bolded phrases to make the scenarios easily recognizable to readers. Due to long planning horizons associated with forest management, we focused on projections for the 2080s (2071-2100).

All of the scenarios project an increase in temperature for all seasons by the 2080s. All of the scenarios project increases in winter, spring and autumn precipitation and decreases in summer, except the Hot/Wet scenario that shows a very slight increase in summer. The Very Hot/Dry scenario is distinct from the other scenarios in its projection for much hotter and drier summers and warmer springs and autumns, remaining within the range of the other models otherwise.

The reference period (1961-90) locations of the bioclimate envelopes that are projected for the study area in the 2080s are currently found as far south and east as Colorado and Kansas, through BC and north to coastal Alaska. The reference period grassland/steppe, savanna and dry forest bioclimate envelopes from the western US are generally projected for lower elevations in the South subregion in all scenarios, and at lower or mid elevations in all subregions in some of the scenarios. The reference period bioclimate envelopes from coastal transition locations are generally projected for upper elevations, mostly in the wetter scenarios. The Alaskan tundra bioclimate envelopes are projected for the highest elevations in some of the scenarios.

Across all of the study area, all three scenarios project bioclimate envelope shifts that reflect decreasing moisture availability at mid and lower elevations – with scenarios differing in the magnitude of change, but not the direction. At the lowest elevations in the South subregion, all of the scenarios project shifts from interior cedar-hemlock (ICH) bioclimate envelopes to grassland-steppe envelopes. At the upper elevations the results are more variable, with one scenario projecting an upward shift of existing ICH climate envelopes, another tending to more coastal transition ICH/CWH (coastal western hemlock), and the third showing a shift to semi-arid Ponderosa pine savanna envelopes, with very limited moist and coastal transition ICH/CWH envelopes at the highest elevations. All of the scenarios project very large decreases in Engelmann Spruce-Subalpine Fir (ESSF) and parkland/woodland bioclimate envelopes – approaching complete elimination in most cases.

**It cannot be over-emphasized that the results presented in this work are only three of many possible futures.**

Additional bioclimate modeling of common tree species' ranges also projects shifts in individual trees species envelopes that are consistent with the projected changes in ecosystem envelopes. Drought resistant and fire tolerant low elevation species' envelopes tend to expand and shift to the north and upslope. Changes in bioclimate envelopes for species currently occurring at upper elevations generally indicate a decrease in occurrence for those species.

## **Fire Impacts**

Regression analysis was used to examine the historical interaction between annual area burned and climatic variables such as spring and summer maximum temperatures and summer precipitation. The resulting relationship was applied to projected changes in those variables from the three climate scenarios to estimate potential future changes in annual area burned. The regression models project steadily increasing area burned in all three subregions for all of the climate scenarios, although there is substantial uncertainty regarding the magnitude of the increases. The minimum increases in average area burned for the 2050s (2041-2070) are 3 to 5 times greater than the area burned during the reference period (1961-90), with average increases of 15 to 300 times.

## **Insects and Pathogens**

Climate change may affect forest health in many ways, some positive and some negative. Summer drought conditions can stress trees, thereby increasing susceptibility to a wider range of insects and diseases. Insects are primarily influenced by temperature, so increases in regional temperature will likely change the distribution, frequency and severity of population outbreaks. Timing of critical life stages of insects are also likely to change, resulting in both increases and decreases in insect levels in the West Kootenays. Pathogen populations however are generally more influenced by precipitation, and so may respond differently than insect populations.

Evidence suggests that climate change may contribute to increased risk of outbreaks of Douglas-fir beetle, western balsam beetle, spruce beetle and western hemlock looper in mature stands. Spruce leader weevil, white pine blister rust, other stem rusts in lodgepole pine, foliar diseases of lodgepole pine and larch, and Armillaria root disease are routinely encountered in plantations, and some of these may increase with climate change. Lodgepole pine plantations in particular appear to be at risk to a wide range of insects and diseases. As climate changes, regeneration will also be subject to attack by insects and diseases found in existing plantations, and new insects and diseases that have only occurred historically in low numbers may reach outbreak levels in future plantations. In addition, diseases that in the past have only caused growth loss may now contribute to tree mortality as observed with larch needle cast and dothistroma.

## **Vulnerability and Resilience**

This project used the overall framework outlined as an integrated Vulnerability Assessment, modified in order to focus on ecological systems. To help in the interpretation of whether different potential ecosystem shifts would result in significant 'vulnerabilities' or not, we considered the theories central to 'resilience' theory, in particular, whether regime shifts and alternative successional pathways were likely.

The Vulnerability Assessment focused on the ecological system (rather than the social or economic system), and looked at the vulnerability of ecosystems in a particular place in relation to the climate scenarios outlined above.

The vulnerability rankings assigned (Very Low to Very high) are relative to within area the study area, not to areas outside of the area. Within this range, low elevation units in the Northern region are consistently given high or very high vulnerability ratings across the three scenarios, as are mid elevation sites in the Mid region of the study area. This somewhat counter intuitive outcome for currently moist and wet cedar-hemlock forests reflects our assessment that the natural disturbance regime in these areas will change substantially (from rare to frequent fires), and the resulting sites will be susceptible to becoming stalled by a lack of seed source for trees appropriate

to the new climate and disturbance regime. Fire and insect analyses suggest these drivers of change have the potential to provide the mechanisms for such profound ecosystem changes.

In terms of consistency of the projections from the three climate scenarios, the low elevation in the North Subregion and mid elevation in the Mid Subregion are most consistent – and predicted to have the highest vulnerabilities in all scenarios. Alternatively, the highest elevation bands in the South, North and to a slightly lesser extent the Mid, have consistently Low and Very Low vulnerability ratings.

Most difficult to know how to interpret the information are the ‘intermediate’ areas – those with either intermediate vulnerability, or with a high diversity of vulnerability ratings across scenarios. For example, the mid elevation band in the North was given Low, Low and Very High vulnerability ratings depending on scenario, while the South mid elevation band was given ratings of Very Low, Very Low and High across the three scenarios. Having a wide diversity of projections results in significant uncertainty about potential outcomes, and makes determination of appropriate management actions particularly difficult to ascertain.

The ecosystem vulnerability analysis provides one aspect of the information required to develop appropriate adaptation options moving forward.

## **Adaptation Options**

Adaptation - changing both practices and perceived measures of success - will likely be required across the full range of forest management practices and management strategies including: adjusting operational decisions about when and how to harvest, changing prescriptions for what species to reforest with, revising management objectives, and reconciling the allowable annual harvest levels with these changes. Creating the understanding and willingness to engage in this process will be a key part of effective adaptation.

It became apparent to the project team during the two years of interaction with West Kootenay practitioners that there is a high level of variability in terms of understanding the need for adaptation, both within, and especially between different branches of forest management. For example, climate change impacts have already prompted changes in practices in strategies around community wildfire protection and more generally within Wildfire Management Branch. However, other members of the forest management community were largely uninformed about the need for change, and the extent of the change that may be required.

Starting the work to identify potential adaptation actions to reduce vulnerabilities to climate change was the end point of the West Kootenay Climate Vulnerability and Resilience project. Using some of the growing literature, input from practitioners at workshops, and the ecosystem vulnerability analysis, we start to develop a framework, and list of potential adaptation actions that can be built upon moving forward.

The ‘right’ adaptations will depend on the characteristics of the forests in the management unit, the legal and policy framework for those forests, and the preferences, particularly about risk management, of the organization and individuals responsible for managing the area. In this project, we outline some specific considerations for various parts of the study area, and at three management scales – landscape/ planning, ecosystem/ stand level and operational.

## **Barriers and Opportunities**

This project was primarily focused on the ecological impacts of climate change, however as resources permitted we also explored the human dimensions of adaptation – the legal, institutional, policy, professional practice and personal aspects of the forest management system in the West Kootenays. The concepts of socio-ecological drivers from the resilience literature, adaptive capacity from climate change adaptation vulnerability assessments, and environmental psychology were also explored as background for this aspect of the project.

A literature review summary regarding key barriers and opportunities in relation to Canadian and BC forest management systems is presented. This is followed by a summary of the input from the West Kootenay practitioners regarding the perceived strengths and opportunities existing today within the local and provincial system, as well as the barriers and gaps, and resulting recommendations. This preliminary research points to the need for a more significant focus on the human dimensions of adaptation to support timely, well thought out adaptations in the West Kootenay forest management system, and in BC generally.

## **Next steps**

This project provides a foundation upon which climate change awareness and adaptation in the West Kootenays can be built. General knowledge about climate change is becoming increasingly enmeshed into the consciousness of broader society, and the rate at which this is occurring appears to have increased quite dramatically, even over the short two-year time window of this work. However, by their nature, all the participants in this project could be considered relatively ‘early adopters’ of climate change adaptation – this includes the working team, the clients, and general participants. Given the relatively new nature of this work, this project should be considered as a first step upon which additional work should be built. Key areas to consider moving forward include:

- **Moving on from the Early Adopters of Adaptation:** extend and diversify the range of people aware of and engaged in climate change and forest management issues in the West Kootenays.
- **From Ecosystems to Values:** in this project we focused primarily on the vulnerability of ecosystems as a first step of analysis. Next steps should include detailed assessment of implications for key values. Implications are wide-ranging and include a) timber supply and allowable annual cut determinations, b) identifying key habitat types at risk and developing appropriate strategies for action, c) identifying key areas of human hazard - particularly with respect to fire management.
- **Delving further into potential climate futures:** we interpret results from three recommended GCM / scenario combinations in this project. It cannot be overstated that the results presented are just a few of the many potential futures, and within this project we only scratched the surface in terms of interpreting the significance of some of these results. Moving forward, further work is needed to delve further into the range of scenarios presented here, and to extend the potential range of climate scenarios more broadly.
- **Understanding resilience:** Conceptually, resilience is an intriguing concept that has engaged this project team fairly significantly. Continuing to explore what thresholds may exist, at multiple scales, for ecosystems (and social systems – something we only touched on here) should continue to be an area of exploration since abrupt, non-linear and potentially catastrophic changes appear likely to be an increasingly significant factor of future systems dynamics.
- **Managing for Resilience:** Moving forward, a meshing of the work done here with general theories on how to promote resilience within forest management would help provide some more specific adaptation options relevant to forest practitioners.
- **Addressing barriers and opportunities for change:** Options developed locally (rather than provincially) may be key to their success.
- **A champion moving forward:** We received consistent positive feedback from participants in this project, who voiced their view that this was a welcome and useful starting place to address climate change issues in forest management in the West Kootenays. Moving forward, identifying a champion - and appropriate funding - to continue this work locally will be key to ensuring that maximum value is extracted from this work, and that effective strategies are identified to address key areas of concern as soon as possible.

## **1.0 INTRODUCTION AND OVERVIEW**

Recent reports by the International Panel on Climate Change (IPCC) confirm that global climate change is underway, and likely to accelerate over the coming decades unless humans make drastic cuts to global greenhouse gas (GHG) emissions (IPCC 2007). In British Columbia, analysis of the last hundred years of climate data confirms that parallel climatic changes are also occurring in this province (Spittlehouse 2008), and in the Columbia Basin (Murdock and Werner 2011). Visible evidence of changes in climate are also becoming increasingly apparent to local people – witnessed through a wide range of changes in a variety of indicators.

Results from downscaled global climate models (GCMs) illustrate the range of potential climate changes for BC over the next century, depending on what assumptions are made about future greenhouse gas emissions. Potential changes for southern British Columbia include increasing annual temperatures and precipitation, decreasing summer precipitation, decreasing snowpack at low elevations, increasing annual and interannual climate variability and an increasing frequency and magnitude of extreme weather events.

The British Columbia government has recognized that the uncertainties associated with climate change demand a forest management approach that differs from the traditional (MoFR 2008). With the establishment of the Future Forest Ecosystems Initiative (FFEI) in 2006, the province began a move toward looking for ways to adapt the forest and range management framework with respect to potential future climates. The province established the Future Forest Ecosystem Scientific Council<sup>1</sup> (FFESC) in 2008 to deliver research grants to support the objectives of the FFEI. This report summarizes some of the findings of one project<sup>2</sup> that was among those funded by the FFESC under their 2009 call for proposals.

This report is the first in the series of reports from this project, and presents a summary of the objectives, study area, the project components and approach. This report also summarizes the results from analyses of potential changes in seasonal climate variables, bioclimate envelope shifts, disturbance regimes and resulting ecosystem vulnerability. Adaptation options, along with barriers and opportunities for adaptation implementation are highlighted. Key lessons learned are also summarized. **For full treatment of each of these subjects, please consult the individual reports available from the project website ([www.kootenayresilience.org](http://www.kootenayresilience.org)), and see a full list in Appendix 1.**

### **1.1 Project Objectives**

This project had three key objectives.

The first was to assess the vulnerability of WK ecosystems to climate change. This was accomplished by identifying potential changes to temperature and precipitation regimes for the West Kootenays for a range of climate scenarios (as recommended by Spittlehouse and Murdock 2011), and interpreting them within a vulnerability framework. The Vulnerability Assessment focused on the ecological systems of the West Kootenays, and incorporated the components of exposure, sensitivity, non-climatic drivers, adaptive capacity, and resilience. The assessment units for the vulnerability assessment are elevational bands of subregions, groups of “regional landscapes”. An evaluation and/or relative rating is provided for each assessment unit for each of the vulnerability components. The results of the Vulnerability Assessment provide one of the key precursors to developing a forest management climate change adaptation strategy. [Report #7 VA supported by Reports #3, #4, #5 and #6].

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<sup>1</sup> Further information on FFESC: [http://www.for.gov.bc.ca/hts/future\\_forests/council/index.htm](http://www.for.gov.bc.ca/hts/future_forests/council/index.htm)

<sup>2</sup> Resilience and Climate Change: Adaptation Potential for Ecological Systems and Forest Management in the West Kootenays. For further information on the project: <http://kootenayresilience.org>

The second objective was to work collaboratively with local forest practitioners, NGOs and other stakeholders, plus technical and other scientists, to collaboratively learn about the potential effects of climate change locally. This objective was undertaken through a series of workshops in which we presented concepts of vulnerability and resilience, and used exercises to present information on climate change and its potential impacts on local ecosystems. The workshops generated technical information which was then incorporated back into the project, and which also served to advance the learnings of some of the local ‘early adopters’ of climate change adaptation within the forest management community in the West Kootenays. Information from the workshops also helped identify elements of adaptive capacity, potential management actions, and policies that will contribute to ecosystem and social resilience in the face of climate change. Additional presentations outside the project workshops were also undertaken to collaborate with other researchers and reach a broader audience. [Report #10, supported by Reports #8, #9 and #11].

The third objective was to advance the science and practice of undertaking a Vulnerability Assessment and in applying concepts of resilience. The analysis, documentation and reporting of outcomes of this case study, together with participant feedback provides a basis for disseminating information on Vulnerability Assessment methodology and the application of resilience concepts to a wider audience. [Reports #2, #7, #10, and #11].

Many aspects of the project were integrated with each other, leading to the series of reports outlined above. The report numbers indicated in parentheses identify which reports deal specifically with each subject, and identify the main report where appropriate. This document – Report # 1 (Holt et al. 2012) – provides an Executive Summary and an overview of all aspects of the project. A list of reports, their lead authors and titles is provided in Appendix 1. All reports and additional presentations and other products created for this work are available on the project website: [www.kootenayresilience.org](http://www.kootenayresilience.org)

## 1.2 The Approach

The primary technical work of this project was aimed at assessing the vulnerability and resilience of the West Kootenay social-ecological system. We focused specifically on the vulnerability of forest ecosystems, and the barriers and opportunities for adaptation within the forest management aspects of the social system. To accommodate the ecological variability across the region we divided the region into seven “regional landscapes,” which we subsequently grouped into three subregions for analysis and ease of presentation (North, Mid and South). For the social aspect, we engaged with a variety of forest management practitioners to identify adaptation options and barriers and opportunities to change.. We exchanged information between the project team and the participants – in both directions – through a series of five participatory workshops.

The first phase of work was to define the dominant drivers and processes for the study area and relate these to the existing ecological and social systems, including the structure and composition of ecosystems and associated forest management systems. Examining the past and present interactions between forest management and ecosystem dynamics grounded the team and clients in a common history of the area, and aided in understanding how the overall system operates. A key element of examining the system dynamics was to use “participatory research”, where scientists, technicians, forest managers and other stakeholders are included in the assessment process.

The second phase was to assess the range of climate change projections for the region, plus the potential impacts of projected climate change on key driving processes, and potential implications of those changes on the structure and composition of ecosystems for each of the subregions. Overall ecosystem vulnerability was assessed using the framework adapted from Fussel and Klein (2006), but focused on the ecosystems themselves, rather than on the full integrated approach that looks at both ecological and social systems concurrently.

The third phase in the analysis was an identification of potential adaptation options that emerged from the vulnerability assessment of ecosystems, and from information generated by the collaborative workshops. In addition, we identified opportunities and barriers that may limit the application of potentially viable adaptation options.

## **1.3 Theoretical Frameworks: Vulnerability, Resilience, Risk and Structured Decision-making**

### **Vulnerability and Resilience**

In this project, we have employed a modified Vulnerability Assessment approach based on the framework outlined by Fussel and Klein (2006). We also incorporated key concepts from resilience theory into the assessment to assist in understanding how, and the significance of, a range of potential ecosystem changes resulting from climate change projected for the study area. In Report #2 (Holt et al. 2012), we provide an overview of Vulnerability Assessments and resilience theory as these approaches apply to assessing the potential ecosystem modifications or transformations that may result from climate change. In Report #7 (Utzig and Holt 2012) we present the results of the assessment for ecosystems in the West Kootenays, and in the discussion we examine the extent to which resilience theory is useful in understanding the potential significance of projected ecosystem changes, including the potential for regime shifts.

This was a change from our original workplan that was structured around applying a resilience framework to undertake the assessment and engage with clients, using the Resilience Alliance workbooks ([www.resiliencealliance.org](http://www.resiliencealliance.org)). As our process developed we decided that the existing format of the RA workbooks did not allow us to systematically move through them in the time we had available in this project – instead we took a series of key ideas presented in the workbooks and restructured them into the format of our own process. At the same time, we changed emphasis in the workshops, to one focusing on Vulnerability Assessment as the core framework, and integrating key resilience concepts within that more linear framework. The terms vulnerability and resilience are often used interchangeably, however we note there is also much confusion about how and where they are applied. Resilience literature assumes that social systems and ecological systems interact to form complex adaptive systems. Complex adaptive systems contain the potential for the loss of resilience<sup>3</sup> and ‘regime shift’ (Scheffer and Carpenter 2003, Walker and Meyers 2004). A regime describes the range of conditions within which a system remains resilient to perturbation. If the system remains within the threshold conditions for the regime, the system can reorganize and persist, remaining fundamentally unchanged. Alternatively, a regime shift can involve profound, often undesirable, changes to system processes and functions, and the flow of goods and services that ecosystems provide.

Humans can influence the resilience of ecological systems by altering them to the extent that they can no longer recover to their previous condition. Humans can also influence resilience by altering the natural resistance to change, as in the regime shift playing out in central BC with the mountain pine beetle (MPB) outbreak (Burton 2010). In that situation, climate change combined with other factors - including wildfire protection policy that contributed to the scale of the outbreak, by creating a landscape with a greater number and contiguity of susceptible stands - thereby reducing overall landscape resilience (Raffa et al. 2008; Burton 2010).

Humans can also respond to existing vulnerabilities that ecological systems have to regime shift by taking actions that reduce their precariousness (Walker et al. 2004), for example by implementing species recovery plans for endangered species. Managing to promote resilience relies on influencing the position of thresholds between regimes, and learning to avoid crossing thresholds (Walker 2005).

Integrated Vulnerability Assessment and resilience approaches have many similarities, including their general goals, preferred study unit (a social-ecological system) and general factors to consider. However, they have typically been employed using quite different approaches and emphasis. The resilience approach – as touted by the Resilience Alliance - tends to promote a more organic, wholistic yet academically theoretical approach to learning about and interpreting implications to a system, whereas the Vulnerability Assessment approach seems to

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<sup>3</sup> Numerous examples of regime shift can be found in ‘The Resilience Alliance and Santa Fe Institute Database. Thresholds and alternate states in ecological and social-ecological systems.’ Available at <http://www.resalliance.org/index.php?id=183>. Resilience Alliance and Santa Fe Institute.

be more systematic or linear, with less focus on the full integration of society and ecology. For this work, even though the focus of the methods changed, we continued to consider both the ecological and social contexts, as promoted by the RA, particularly in terms of how to engage with our client group. Within the scope of the Vulnerability Assessment, we focused on ecosystems for the analysis, and separately assessed the linkages to forest management adaptation, rather than undertaking a full-scale assessment of the full socio-ecological-system.

Our rationale for continuing to use both vulnerability and resilience – rather than choosing one over the other – was primarily that both concepts / terms are widely used in the context of forest management – at both the national level and within British Columbia. However, while the language of resilience has also been adopted by BC MoFR and within academia (e.g., SFU now is a “resilience node” of the resilience alliance) specific application of the concepts had not been tested locally. Overall we do not see fundamental contradictions between the two sets of terminologies and ideas, however, we did find that application was more straightforward using the vulnerability approach than using the methodology set out in the RA workbooks. At the same time, we found it useful to use resilience ideas as a more conceptual framework for how to think about ecosystem functions and transitions. While ‘workshopping’ these various concepts and approaches we recognized that for some people involved in the project, thinking about the theories helped in understanding how systems work. For others, the approach was too ‘academic’ and was not helpful in terms of shedding light on the issues.

## Risk analysis

Risk analysis is a formal process used widely in resource management to identify the risks associated with a series of actions. Risk analysis combines the probability that an event will occur with the emergent consequences if it does occur. Risk, vulnerability assessment and resilience in many ways can be thought of as ways to provide information on which to build a decision-making framework. We did not take a risk assessment approach in this project, but identify it as a potential alternative approach, or as a tool that can be used for detailed considerations within an overall Vulnerability Assessment..

## Structured Decision-making

In climate change adaptation, vulnerability assessments, resilience, and risk management, are most often used to evaluate the relative importance of addressing the impacts of climate change and assessing various options for adaptation. However, the challenge for decision-makers is to decide “what to do” to reduce impacts, or in some cases, to capture opportunities from climate changes. Based in decision theory and risk analysis, structured decision making (SDM) encompasses a simple set of concepts and helpful steps, rather than a rigidly-prescribed approach for problem solving.

Key SDM concepts include making decisions based on clearly articulated fundamental objectives, dealing explicitly with uncertainty, and responding transparently to legal mandates and public preferences or values in decision making. The process marries value-focused thinking and technical information in a flexible planning framework - often using graphic presentation tools to highlight tradeoffs between alternatives.

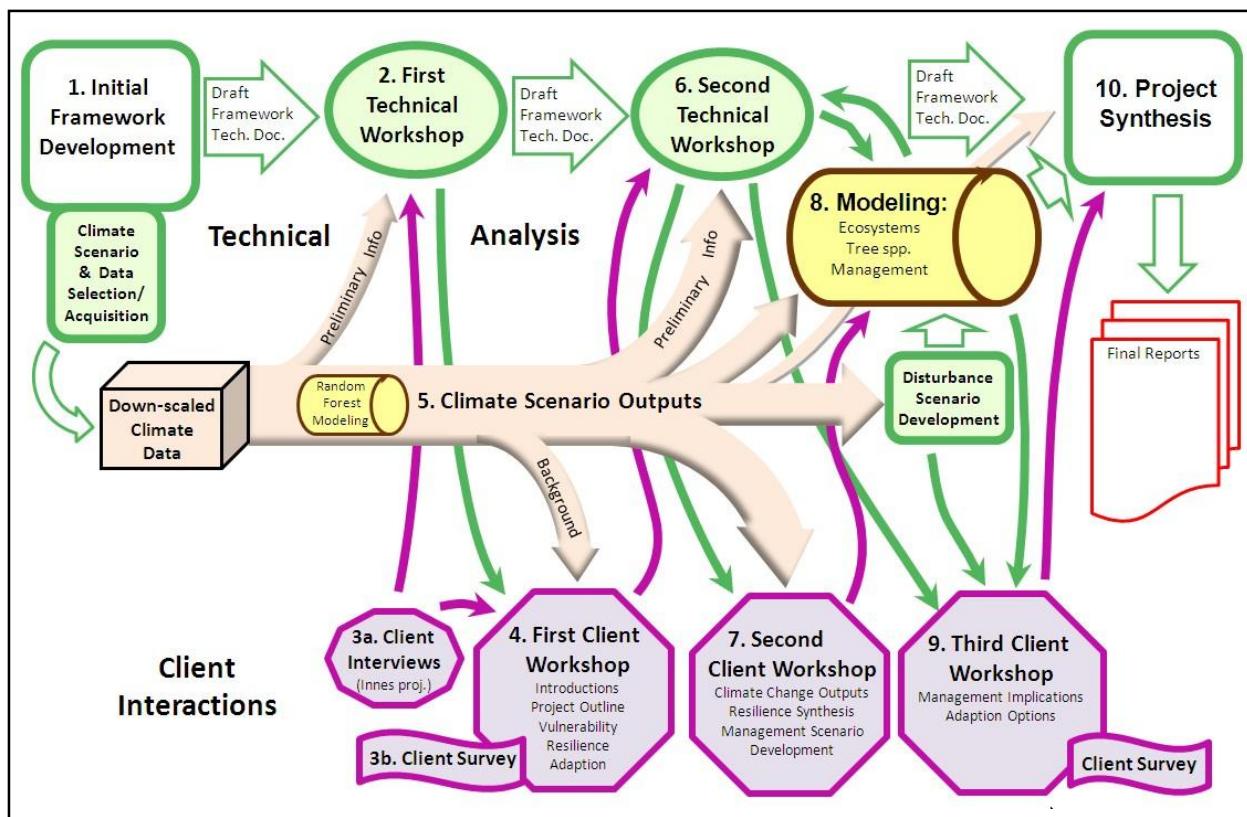
SDM includes six distinct steps: 1) define the problem and clarify the decision context; 2) define the management objectives and set evaluation criteria; 3) create alternatives; 4) estimate consequences related to evaluation criteria; 5) evaluate trade-offs and decide; 6) implement and monitor.

We provide an overview of the process for undertaking SDM (Report #2, Holt et al. 2012), and we ‘tested the process’ to a limited degree, by working through examples of the process in the final workshop with practitioners (Report #10, Pinnell 2012). We suggest that as adaptation moves forward in the West Kootenays, SDM could provide a useful framework within which to further identify priorities for action, and to identify which of the potential suite of actions may be most appropriate.

## 1.4 Outline of Steps Taken in the Project

The following ten steps summarize the principle activities and methods (see also Figure 3) that were proposed in the project proposal – with comments in **BOLD** on how each was implemented:

1. Develop an initial framework for structuring the vulnerability and resilience assessments, including issues of scale and ecosystem entities. Based on existing research and expert opinion, identify system drivers and disturbances and develop an historical profile of the systems. Confirm the key players and outline the existing management system. Based on a review of system dynamics, develop a conceptual model of change, including potential threats and vulnerability of focal systems. Summarize results in a preliminary draft technical report. **A technical report was created and used as a working draft in the first technical and practitioners workshops.** This report was then built upon, resulting in the series of final reports for the project. Some of the technical aspects of the work were modified as it was realized that the RA workbooks were difficult and time-consuming to implement – however, the overall approach to the work remained similar, but with less focus on *a priori* development of complex models of ecosystem functioning, and more focus on developing and interpreting the climate change and bioclimate projections themselves as a first step. We continued to use elements of the RA workbooks, but changed the format in which we applied them to fit within a more structured approach.



**Figure 1. Schematic diagram showing the sequencing and relationships between the key project components. The numbers relate to the steps outlined in the text. Green boxes and arrows indicate technical aspects, the block box climate data from Global Climate Models, the brown cylinders modeling components, and the purple shapes interactions with clients. Shaded shapes indicate steps with significant involvement by people outside the primary project team.**

2. Undertake the first of two technical workshops. Review and discuss initial framework and draft technical report with the technical group. Revise and elaborate on framework and draft report based on workshop inputs. **Done and incorporated into the delivery of the project.**
3. In collaboration with Innes FFSEC project, forest practitioners, and other stakeholders, explore local understanding of the potential impacts of climate change, the institutional capacity to manage climate change impacts, and the potential for local application of resilience theory. **In workshops, we worked through concepts of vulnerability and resilience (see #4), and created ‘impact diagrams’ to explore potential implications of the information generated on potential changes in climate. We also employed a survey to understand how the people broadly involved in forest management in the West Kootenays view climate change and its challenges and opportunities. The Innes project did not undertake the type of modeling originally foreseen, so collaboration at that level did not occur.**
4. Undertake the first workshop for clients. Introduce client group to the project, and the concepts of vulnerability and resilience assessments. Facilitate discussions with participants regarding the scale and focus of the assessments, linkages between the past and present states of the systems, key processes, disturbances, threats, vulnerabilities, potential thresholds and the potential for alternate regimes. Receive preliminary client input into management scenarios for process modeling (step 8). Based on workshop results, update draft technical report. **Done and output incorporated throughout the project, resulting in input into final reports and key learnings from the project. It is difficult to quantify the benefits associated with the intangible nature of ‘learning’. However, we received very positive feedback from participants in this and the other workshops.**
5. Climate Information. Identify a suite of climate variables required for ecosystem modeling and desired outputs. Identify scenarios and climate models for data acquisition. Acquire downscaled climate modeling and baseline data. Complete preliminary analysis of outputs. Prepare presentation materials for use in workshops, website presentations and written reports (inputs to steps 6, 7, 8, 9, 10). **Significant area of project work, facilitated by modeling from David Roberts (U. Edmonton). Obtaining access to the work by Roberts resulted in detailed local information on potential ecosystem shifts in relation to four GCM model / and emissions scenarios being available. Significant time was spent analyzing and presenting this information to the range of participants in the project. Because modeling outputs were available, this became a considerably larger element than originally envisioned, and provided a solid grounding of information for this stage of the project and moving forward. Well received by participants in the process, though challenging to transmit such significant amounts of technical information to a broad audience with differing backgrounds.**
6. Second technical workshop. Present climate modeling results. Identify potential ‘critical’ impacts from climate change – those impacts where the magnitude, timing and/or irreversibility make them especially significant, those that significantly reduce ecosystem function, or impacts that cross ecological thresholds. Review and discuss draft technical report including reassessment of the hypotheses developed in step 1. Focus on refining conceptual models of ecosystem change and regime shifts, including a focus on defining alternate states, thresholds and transitions, in light of climate modeling results. Consider potential interactions between thresholds and identify potential resilience and adaptability attributes. Update and revise technical report (inputs into scenarios for step 8). **The team and participants engaged in discussion of these approaches and concepts as outlined, but found conceptual difficulty in developing any detailed hypotheses. It is difficult to gauge the utility of the learning gained from the discussions, though informal feedback was positive from participants. Identified one of the key ‘issues’ with the resilience approach in attempting to apply a very academic focused series of concepts in a setting where most participants are interested primarily in the outcome not the process. Alternatively, some specialized participants (e.g. research focused staff) were interested in engaging at this level. Difficult to maintain the engagement of academics in an external process such as this. Internal to the project team however, we found utility in engaging with technical resilience concepts in helping to understand the significance of the projected changes in ecosystems, and to discuss the importance of ecosystem transition with the forest practitioners at the workshops.**

7. Undertake the second of three client workshops. Present climate modeling results and update clients on technical components of resilience process. Facilitate discussion regarding possible revisions to the clients' preliminary inputs on management scenarios for process modeling in light of climate change modeling results (inputs to step 8). **Undertook this work, but focused more on specific results from the climate modeling, and presentation of how such changes could tie into changes to key drivers identified in earlier workshop.** Time required to work through this information, incorporating sufficient hands-on exercises to make the information comprehensible was significant, and much larger than originally anticipated.
8. In collaboration with FFESC Innes project undertake modeling of key processes as feasibility allows (e.g., tree regeneration using TACA [Nitschke and Innes 2008]). Develop a draft synthesis of resilience understanding for focal systems. Develop draft management interventions. Report on process modeling results, draft resilience synthesis, implications of modeled management scenarios. **Linkage to Innes project did not occur at this level of technical detail (no modeling results from Innes' team became available) – although significant efforts were made to collaborate (e.g. various meetings and ongoing discussion with W. Klenner / H. Harshaw / J. Nelson etc).** Internally our team explored the use of TACA, but focused instead on adapting existing model results for ecosystems and tree species and exploring their detailed implications for our study area. Internally, our team developed fire modeling work and compiled information on insects and disease since these were identified as key ecological drivers.
9. Third client workshop. Present results of ecosystem modeling and summarize management implications. Facilitate discussions regarding potential regime changes, the adaptive cycle, interactions at multiple scales, adaptive capacity, potential management interventions (multiple levels – stand, landscape, policy), monitoring and adaptive management. Determine next steps. Participatory evaluation of project and process by the participants. Summary of participant discussions (input to step 10). **Although we moved away from using the RA workbooks as the basis for interacting with our client group, we applied some of the general strategies and discussion items in our workshops. The resilience approach suggests a framework that extends beyond participation to individual and group learning (e.g., Centre for Community Enterprise 2000, Resilience Alliance 2007a,b,c), and while we recognise that this may be a laudable goal, we found that it was time consuming and challenging to enact. Our original intention was, through the series of workshops (two technical and three for clients), that participants would develop hypotheses about key drivers of resilience across WK ecosystems. These hypotheses would then be examined under a range of climate change and management scenarios to better understand how key management activities (e.g., strategic planning and stand treatments) interact with scenarios of climate change to influence ecological resilience. We were relatively successful in developing the ecosystem resilience aspects of this work, but less successful – largely due to time constraints – in developing the link to key management activities within the workshop format.**
10. Synthesis - Final Reporting. **We present the results of this work in 11 separate reports. A list of these is found in Appendix 1. The reports and various presentations created for the workshops are available on the project website.**

## 2.0 THE STUDY AREA: FOCAL ECOLOGICAL AND SOCIAL SYSTEMS

The study area for this project is located in southeast British Columbia, and outlined in Figure 2. The study area is primarily composed of the Columbia Valley River valley between Beaton Arm and the US border, and the Slocan, Kootenay, Lardeau and Duncan valleys. There are numerous small communities scattered throughout the study area. The communities include Nakusp and Trout Lake in the north, Castlegar, Rossland and Trail in the southwest, Creston and Yahk in the southeast, and Kaslo, Nelson and New Denver in the center.

## 2.1 Ecological overview

The study area includes the eastern flank the southern Monashee Mountains, the central and southern Selkirk Mountains, and the western flank of the central and southern Purcell Mountains. This is a portion of what is commonly referred to as the “Interior Wet Belt” or the “Interior Temperate Rainforest”.

The main valleys are generally north-south trending and U-shaped, with either gently sloping terraced valley bottoms, or are filled with natural lakes or reservoirs. Valley bottom elevations range from 420m in the Columbia, 530m in the Kootenay, and up to 720m at Trout Lake. In the northern portion of the area, mountain ranges are steep and highly dissected, with main ridgelines generally in excess of 2150m in elevation, and peaks reaching up to 3200m. In the southern portion, the mountain ranges are moderately dissected with generally rounded ridgetops varying from about 1650 to 1980m, with occasional peaks to over 2300m. The geology of the area is varied, including a range of folded and faulted sedimentary and metamorphic rocks, as well as significant intrusions of granitic plutons. The topography and terrain are typical of glacial source areas, with extensive colluvial materials and active glaciation at the upper elevations, morainal and colluvial materials of variable depths at mid elevations and extensive glaciofluvial and morainal materials in the valley bottoms. An extensive floodplain and delta occur where the Kootenay River empties into Kootenay Lake from the south. Soils are generally medium to coarse textured Podzols and Brunisols reflecting the glacial terrain and a moist climate.

The northern portion of the area is dominated by vegetation of the wetter subzones of the Interior Cedar Hemlock (ICH) and Engelmann Spruce – Subalpine Fir Zones (ESSF), typical of a moist to wet southern interior climate. The area also includes significant areas of parkland and Interior Mountain Alpine (IMA). Natural disturbance regimes are mainly long intervals of low intensity gap-replacement events, interrupted by infrequent stand-replacing events (mainly high intensity crown fires).

This grades to drier subzones of the ICH and moist to dry subzones of the ESSF in the southern portion of the study area. In the south, the subdued topography and drier climate eliminates the presence of IMA, although there are occurrences of upper elevation woodland and limited parkland. Natural disturbance regimes in the south range from relatively infrequent stand-replacing fire regimes at the upper elevations to frequent low intensity fire regimes at lower elevations on southern aspects.

Diversity of fish and other aquatic species is high, reflecting the wide range of lake, river and stream habitats present in the study area. Terrestrial and avian faunal diversity mainly reflects those species found in moderately to densely forested environments, with lesser occurrences of species found in drier habitats with mixed fire regimes or fire-maintained ecosystems in the south.

## 2.2 Socio-economic Overview

The focus of the societal aspect of this project was on a broadly defined forest management community. This included people actively engaged in forest and land management including forest licensees, private land managers, government employees (federal, provincial, regional, municipal), water managers, Environmental Non-governmental Organizations (ENGOS), educators (college, university), fisheries and wildlife biologists and

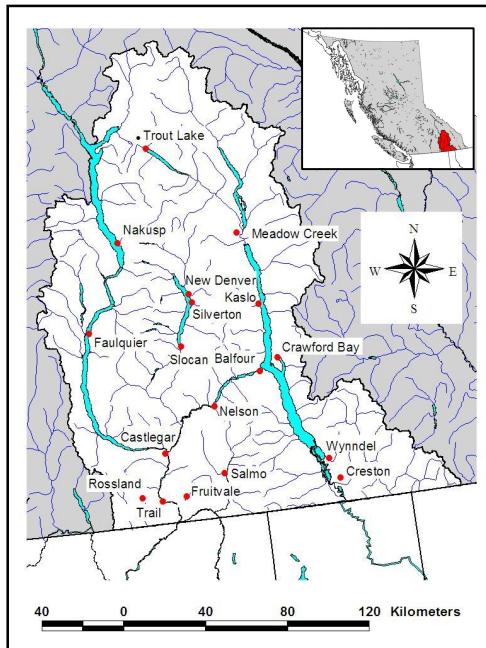


Figure 2. Study area.

commercial recreation operators. In addition to the obvious forest products of timber and fibre, the forest ecosystems of the study area are also important to other economic sectors in the region, including all-season commercial tourism, wildcrafting, hunting and backcountry guiding, and through their impact on the hydrologic cycle, water flows for electrical generation and agricultural irrigation. Forest ecosystems also provide numerous ecological services, including domestic and irrigation water supplies, erosion control, flood mitigation, recreation opportunities, as well as aesthetic and spiritual values.

Forest licensees form an important part of this social system due to the large proportion of Crown land they manage. The Kootenay Lake and Arrow Timber Supply Areas (TSAs) are diverse in terms of numbers and types of forest license holders, including 2 Tree Farm Licenses (TFLs), 12 volume-based Forest Licenses, extensive area of BC Timber Sales management, 29 woodlots and 5 Community Forests (see Figure 3). The study area includes one pulp mill and 7 moderate-sized timber processing facilities. Wood is also trucked out of the study area to two large processing facilities located to the east and west.

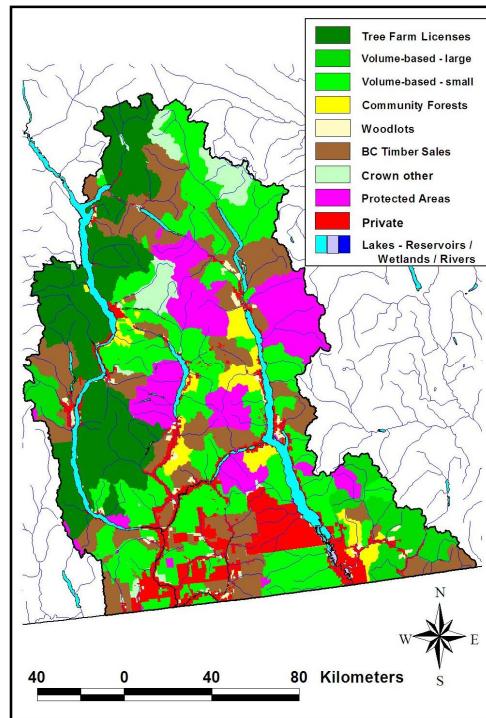
At a broad level the study area can be divided into three classes based on primary use: timber extraction, conservation and intensive development (rural/ urban and agricultural land). Timber extraction can be further divided based on tenure types: large area-based Tree Farm Licenses (TFLs), large and small volume-based tenures (Chart Areas), area-based Community Forest Licences, area-based Woodlots, and large parcels of private forest land, mostly Managed Forests (see Figure 3). Conservation lands include Protected Areas and private lands managed primarily for conservation purposes. Other uses and values which are important to the ecological and socio-economic resilience of the region, such as critical wildlife habitat, commercial and non-commercial recreation, domestic and irrigation watersheds, and fisheries values also overlap these primary tenures to varying degrees.

The communities and local economies of the West Kootenays have traditionally been tied to, and continue to depend on the goods and services supplied by local ecosystems. This ranges from long-term subsistence use by First Nations, timber and pulp production, streamflow for community water supplies, and non-timber forest products, to a tourism industry based of wildlife and fisheries abundance and aesthetic qualities of the forests. Compared to many regions of the province, the dependence on a traditional forest industry is relatively weak.

## 2.3 Ecological and Social Controlling Variables

The Resilience Alliance workbooks ask participants to reflect on the broad study area, and identify how the system functions and what external pressures have influenced in the past, now, and into the future. We used this guidance to lead various discussions in workshops.

Compared to many regions of the world where vulnerability and resilience assessments are underway, BC's southern interior is a relatively natural landscape. Identifying how the system functions naturally is therefore an important first step in understanding how to reduce vulnerabilities and manage for resilience. Identifying the variables that control the system is the key way to understand how changes in these processes may affect the system into the future.



**Figure 3. Forest tenures.**

The ecological and social systems interact with each other as the implementation of forest management policies and activities begin to affect changes to the structure and composition of ecosystems, and in some cases driving processes (e.g., fire management, dams and flooding). Conversely, ecological processes can influence the application of forest policies and management (e.g., mountain pine beetle infestations and AAC determinations).

Within the local context, we worked collaboratively at the workshops with practitioners and science experts to establish an historical timeline of past driver impacts and system responses. We discussed scales and how factors influence outcomes at multiple scales, and identified some key environmental and social drivers for the region. Ecologically – key drivers identified were various aspects of climate (extremes, snow, drought, general weather patterns), fire, invasive species, insects and disease, keystone wildlife species and vegetation succession.

From a forest management perspective we identified key drivers that interact with the ecological factors to be timber supply management (AAC), fire management policy, global timber markets, dam construction, general urbanization, reforestation, lack of forward-thinking planning, old growth liquidation, forest tenure ownership, roads and utility corridors and water users.

The Resilience Alliance workbooks asked us to identify the extent to which historic actions had altered the current functions, and whether this provided insight into how the system may change in the future. This approach framed the discussions and were useful in putting people's perspectives on the table, and in grounding everyone in a common history of the region. However, the intention to pull out patterns of change - linking ecological responses to changing social interventions/attitudes over time (e.g., new policies or management systems), and to also examine social responses to ecological changes (e.g., changes in policies or management systems) was a challenge. These discussions did however provide a foundation for later work regarding opportunities and barriers to adaptation, and implementing a new direction for management in time of significant uncertainty.

**Table 1. Some examples of past human intervention that led to ecological changes in the forested landscape.**

Policy/management system:	Examples of responses:	Scale
Early railroad development and mining exploration	Loss of forest cover due to increased fire ignitions	Landscape / stand
Building dams	Loss of low elevation cottonwood stands and wetlands; loss of salmon	Landscape/ watershed/ stream reach
Fire suppression	Change in age class distribution Increase in MPB susceptible and fire-prone stands	Landscape / watershed / regional
Over hunting and fishing	Caribou depletion; loss of fisheries	Landscape / watershed
Harvesting patterns	Old-growth depletion; creation of OGMA's	Landscape/ stand
Agriculture expansion	Habitat conversion; invasive plant introduction	Stand
TSR policy	Dependence on high AAC and reliance on enhanced silviculture	Regional / landscape / stand
"War in the woods"	Initiation of CORE, PAS, FPC, etc	Provincial trigger Affecting regional / landscapes / stand
Intensive recreation development/ motorized recreation	Golf courses displacing low elevation habitat; snowmobiles displacing caribou	Stand / landscape
Grazing tenures	Riparian degradation; modification of successional	Stand / landscape

Policy/management system:	Examples of responses:	Scale
	patterns; loss of predators; invasive species expansion; grassland degradation	

## 2.4 Studying social-ecological systems

Both a full integrated vulnerability assessment and the approach outlined by the Resilience Alliance promote a concurrent and integrated analysis of how ecological and social systems integrate and feed back into one another. The RA promotes this broad systems thinking as an integral part of the analysis approach, whereas the vulnerability approach promotes an ‘add in’ of more integrated pieces as the assessment becomes more complex.

Full analysis of all aspects of the social-ecological-system (SES) was outside the scope of our project proposal, due to the high level of engagement required from a very broad cross-section of individuals, and the significant time involved. Instead, we focused on the vulnerability of the region from an ecosystem perspective and made the linkage to the socio-economic by looking at key adaptation options and the barriers and opportunities for implementing them within the forest management sector.

## 2.5 Vulnerability and Resilience of What?

Given the scale and uncertainty of the projected climate change, the size and complexity of the study area, and the limited time and resources available for the assessment, we focused our assessment to broad-scale generalized ecosystems, with limited assessment of the associated forest management community. Traditionally in BC the logical unit for assessment would have been a Biogeoclimatic unit or an Ecosection. However, because both of the those classification systems are based on an assumption of a relatively stable climate and species distribution, neither classification system will adequately portray the range of niches and biological diversity of the province as the impacts of climate change proceed over the coming decades. As climate change proceeds, species distributions will respond species-by-species, depending on their individual tolerances and responses to changing conditions (Parmesan 2006). As this occurs, many species assemblages and ecosystems within BEC units will begin to disaggregate. As well, as climate envelopes evolve into new combinations of climate variables, today’s BEC units will also disintegrate and/or evolve into new species assemblages with newly defined climate envelopes. To fill this classification void, we developed an alternative system for identifying broad ecosystems<sup>4</sup>, based on environmental factors that will remain relatively constant as climate change proceeds (i.e. enduring features). Macro topography plays a key role in determining the distribution of climate envelopes in BC, and will remain a relatively constant factor for the time scales under consideration (decades and centuries).

Using topographic breaks and uniform elevational sequences of currently mapped biogeoclimatic units we defined geographic areas with relatively homogenous regional climates (Figure 4a). Each of these areas are defined as a unique “Regional Landscape” (RL). Climatic variability within the RLs is primarily determined by aspect and elevation, with some contributions of meso/micro topographic elements. The climatic variation between RLs is assumed to result principally from macro topography interacting with weather systems. Because macro topography is stable in the face of climate change, we assume that the climate of individual RLs will likely remain relatively homogeneous even as climate change proceeds<sup>5</sup>. We subsequently grouped the RLs into three subregions for analysis and ease of presentation (North, Mid and South – Figure 4b).

<sup>4</sup> These were developed in cooperation with Deb MacKillop of the BC MoFLNRO.

<sup>5</sup> This assumption would be less likely to be valid under a severe climate change scenario where there may be significant shifts in the patterns of weather systems. For example if there is a significant shift in continental vs. maritime influences or the long-term seasonal pattern of the jetstream.

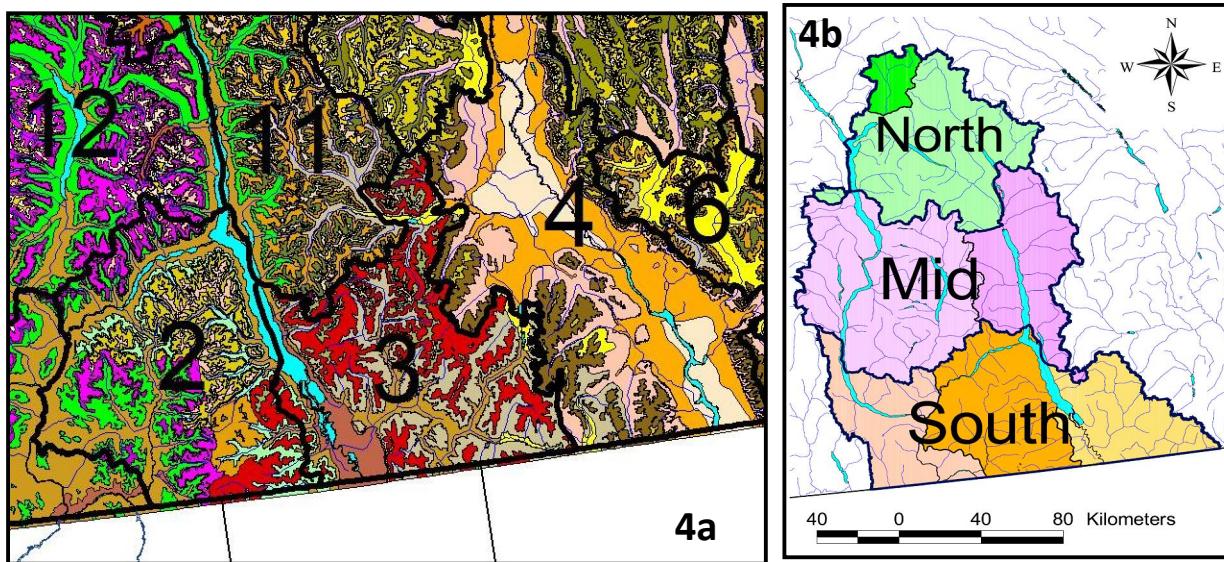


Figure 4. (4a) An example of regional landscapes, outlined in heavy black, and current BEC units, shown in contrasting colours. (4b) Regional landscapes grouped into subregions for the study area.

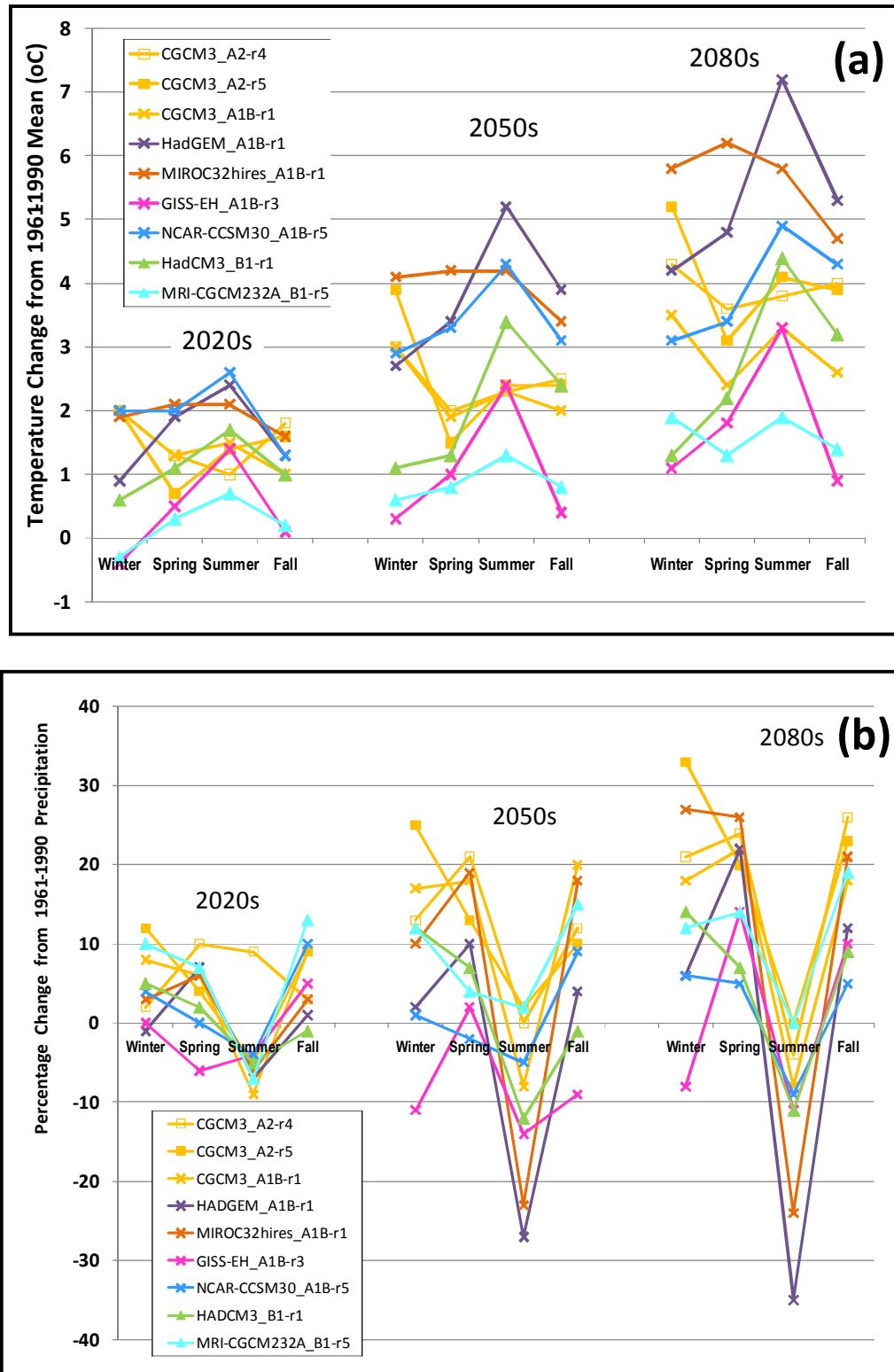
## 3.0 CLIMATE CHANGE

### 3.1 Projected Changes in Seasonal Climate

To explore the range of potential climate projections for the study area, nine climate scenarios were selected for investigation (see Utzig 2012a for full results). The selection included seven General Circulation Models (GCMs) and three greenhouse gas (GHG) emission scenarios, representing a cross-section of projected changes in annual temperature and precipitation. The scenarios selected were based on recommendations by Murdock and Spittlehouse (2011), and a desire to explore the potential variation between GCMs, emission scenarios and individual runs.

Based on a comparison of model outputs and recorded climate data, all of the models were reasonably capable of simulating seasonal patterns of temperature for the study area during the baseline period (1961-90), although on average, they tended to slightly under-estimate temperatures in all seasons except summer. The seasonal pattern of spring, summer and fall precipitation for the reference period was also reasonably well simulated by most of the GCMs, although slightly under-estimated on an absolute basis. Winter precipitation however, was significantly under-estimated by all of the GCMs. This is likely mainly due to the resolution of the global climate models, and their inability to fully capture the effects of topography on precipitation. These results provides us with some evidence that most of the models tested are potentially useful for projecting future temperatures and precipitation for the study area, with some concern for winter values.

Future projections for the study area, estimated that by the 2080s, winters, springs and falls would be warmer by 2 to 5°C, and summers warmer by 3 to 7°C (see Figure 5). Precipitation was projected to increase by 10-25% in the winter, spring and fall, and in the summer either remain unchanged, or decrease by up to 30%. The most obvious trend shown by the models was an increase in summer moisture stress. The other major conclusion was that variability between GCMs exceeded variation due to emission scenarios, indicating that there is still significant uncertainty in our understanding of how the global climate system operates, and specifically how it will respond to increasing GHG concentrations.



**Figure 5. Comparison of projected mean seasonal temperature (a) and precipitation (b) for the study area as modeled by various GCMs for the 2020s, 2050s and 2080s (colours indicate individual GCMs, symbols indicate individual scenarios, open and closed symbols indicate differing runs).**

## 3.2 Implications for ecosystems and key controlling processes

Climate change is expected to impact or cause changes to many elements of ecological systems. These include broad categories of impacts – direct and indirect impacts, and those affecting species, communities and broad ecosystems at different scales in both the aquatic and terrestrial realms. At the species level, food and habitat supply changes will alter population distributions across landscapes. Cumulatively, communities will alter as species come and go. The implications of such changes broadly will depend partly on the functional importance of individual species – shifts in keystone, engineer or foundation species may fundamentally alter how a system functions causing ‘unexpected’ changes in character and function. Changes to processes are often likely to be significant at some scale – changes in timing, severity and nature of disturbances may fundamentally shift whole systems. Fire impacts are the most obvious example for Kootenay ecosystems, though how fire frequency and severity may change is complex since temperature, moisture, fuel and fire management all interact to determine how fire will ultimately alter forest structure. Transition to new regimes may be catastrophic and traumatic for different aspects of society.

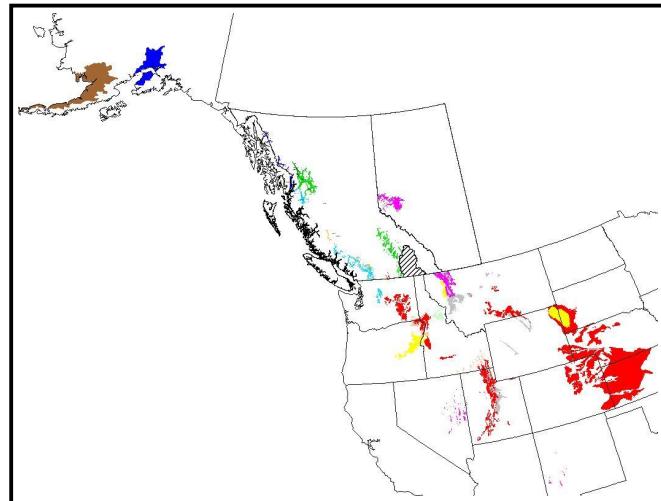
In this analysis we focused our attention primarily on the bioclimate shifts as they refer to whole ecosystems and how they may respond to wholesale shift in climate. In addition, we undertook to analyze potential changes in fire regimes since this has both direct and indirect implications for ecosystems and human society in this region, and we explored what is known about changes to insects and disease – another key disturbance agent that affects mortality of individual trees and potential is also a mechanism for ecosystem state transition.

### 3.2.1 Bioclimate Envelope Modeling

Three climate scenarios that generally illustrate the range of climate projections for BC were selected for ecosystem bioclimate envelope modeling with PRISM-based climate data and RandomForest (see Utzig and Holt 2012 for methods and full results). The three scenarios include combinations of three GCMs and GHG emission scenarios: a “**Warm/Moist**” scenario with low emissions (HadCM3\_B1), a “**Hot/Wet**” scenario with high emissions (CGCM3\_A2), and “**Very Hot/Dry**” scenario with moderate emissions (HadGEM\_A1B). We use the bolded phrases to make the scenarios easily recognizable to readers. Due to long planning horizons associated with forest management, we focused on projections for the 2080s (2071-2100).

All of the scenarios project an increase in temperature for all seasons by the 2080s. All of the scenarios project increases in winter, spring and autumn precipitation, and decreases in summer, except the Hot/ Wet scenario that shows a very slight increase in summer. The Very Hot/Dry scenario is distinct from the other scenarios in its projection for much hotter and drier summers and warmer springs and autumns, remaining within the range of the other models otherwise.

The reference period (1961-90) locations (i.e. current locations) of the bioclimate envelopes that are projected to occur in the study area in the 2080s are currently found as far south and east as Colorado and Kansas, through BC and north to coastal Alaska (see Figure 6). The reference period grassland/steppe, savanna and dry forest



**Figure 6. Reference period (1961-90) locations of bioclimate envelopes that are projected to occur in the study area in the 2080s based on results from RandomForest analysis of three climate scenarios. Colours of source areas are consistent with Figure 7.**

bioclimate envelopes from the western US are generally projected for lower elevations in the South subregion all scenarios, and at lower or mid elevations in all subregions in some of the scenarios. The reference period bioclimate envelopes from coastal transition locations are generally projected for upper elevations, mostly in the wetter scenarios. The Alaskan tundra bioclimate envelopes are projected for the highest elevations in selected scenarios.

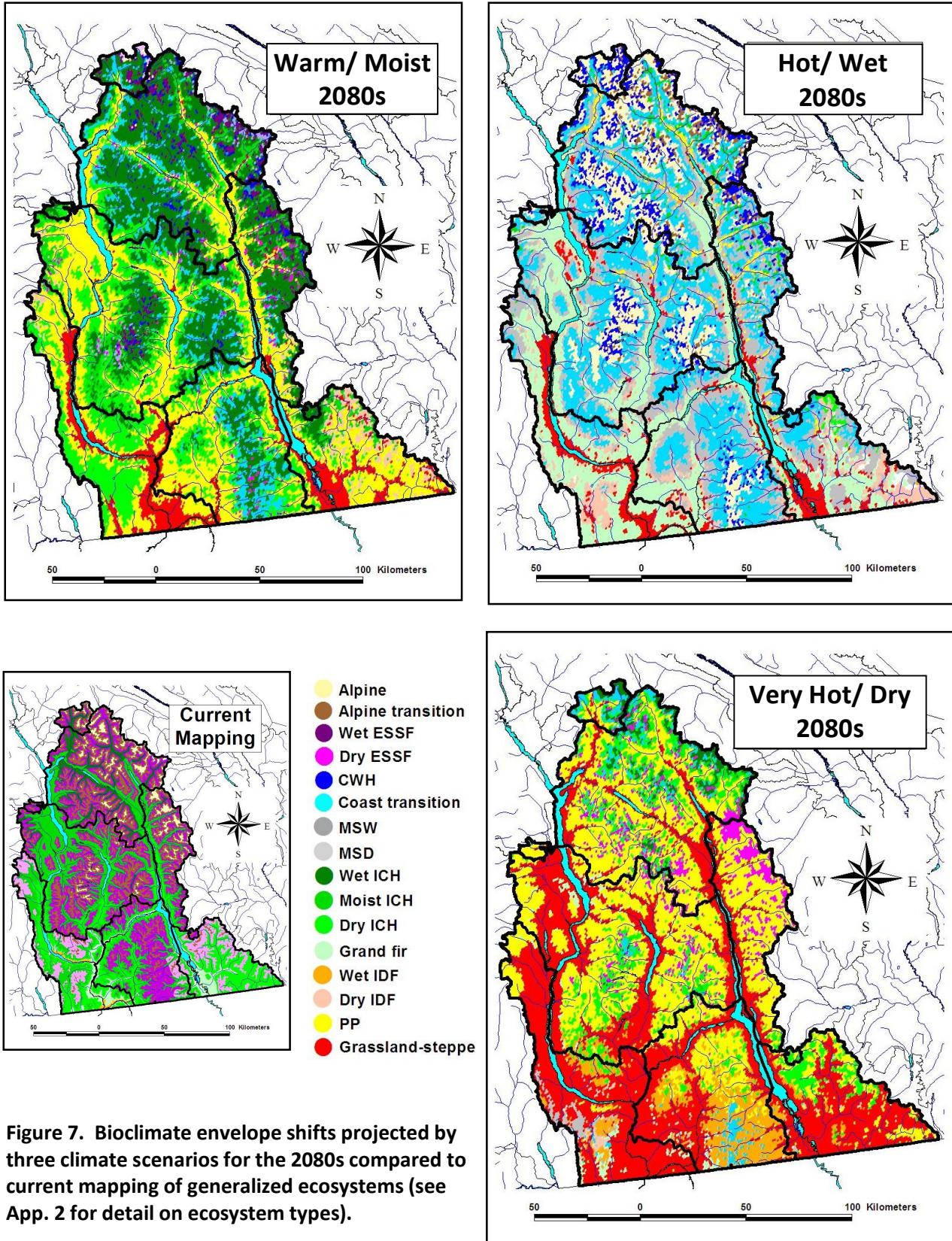
The projected changes in bioclimate envelopes for the study area in the 2080s are shown Figure 7. All of the scenarios demonstrate significant changes by the 2080s, with variation in results depending on the variation in climatic variables discussed above. A summary of the implications from the three scenarios:

- **Warm-moist scenario (HadCM3\_B1):** the lowest temperature increases and minimal precipitation increases – lower elevations shift to grassland-steppe bioclimate envelopes in the South subregion and ponderosa pine savannas in the North; mid elevations are a combination of ponderosa pine savannas and coastal transition/ dry interior cedar-hemlock (ICH) forest bioclimate envelopes; and, upper elevations are dominated by moist and wet ICH envelopes;
- **Hot-wet scenario (CGCM3\_A2):** greater increases in temperature and precipitation – grassland-steppe bioclimate envelopes for the lowest elevations of South and parts of the Mid subregions, along with some dry interior Douglas-fir (IDF) and grand fir/Douglas-fir forest envelopes; mid elevations of the South and Mid subregions and lower to mid elevations of the North are dominated by grand fir/Douglas-fir forest and dry montane/sub-boreal spruce (MSD); upper elevations of the whole study area mainly shift to coastal transition ICH/ coastal western hemlock (CWH) and alpine envelopes; and,
- **Very hot-dry scenario (HadGEM\_A1B):** significantly hotter and drier summers – all lower and mid elevations in the South subregion shift to grassland-steppe bioclimate envelopes, as do the lower elevations in the Mid and North subregions; mid elevations generally shift to ponderosa pine savanna envelopes; the highest elevations are dominated by dry and moist ICH, with minor dry Engelmann spruce-subalpine fir (ESSF); in the South and North at upper elevations, there is also some coastal transition ICH/CWH and mixed IDF/MSD in the western portion of the South.

**CAUTION:** To assist BC readers envisioning the type of climatic environments that may occur in the future, the bioclimate envelopes have been designated with names of the most similar ecosystems that currently exist in BC. **Although these bioclimate envelopes are described with ecosystem names that are familiar, it should not be assumed that the future ecosystems that will develop in these climate envelopes will be identical to ecosystems that readers are familiar with.**

Across all of the study area, all three scenarios project bioclimate envelopes shifts that reflect decreasing moisture availability at mid and lower elevations – only differing in magnitude of change, but not direction. At the lowest elevations in the South subregion, all of the scenarios project shifts from ICH bioclimate envelopes to grassland-steppe envelopes. At the upper elevations the results are more variable, with one scenario projecting an upward shift of ICH climate envelopes, another tending to more coastal transition ICH/CWH, and the third showing a shift to semiarid ponderosa pine savanna envelopes, with very limited moist and coastal transition ICH/CWH envelopes at the highest elevations. All of the scenarios project very large decreases in ESSF and parkland/woodland bioclimate envelopes – approaching complete elimination in most cases.

It cannot be over-emphasized that the results presented here are a few of many possible futures. Bioclimate envelope projections have numerous sources of uncertainty, including the choice of modeling technique and the error associated with downscaling (e.g., Mbogga et al. 2010, Diniz-Filho et al. 2009, Pearson et al. 2006). As shown in Figure 7, the choice of GCM, as well as assumptions about future greenhouse gas emissions can significantly affect the predicted outcomes from an analysis. Other studies have also found these variables to be major contributors to uncertainty (e.g., Mbogga et al. 2010, Diniz-Filho et al. 2009). Analysis also identified the potential for occurrences of novel or non-analogue climate envelopes in the projections from all three climate scenarios.



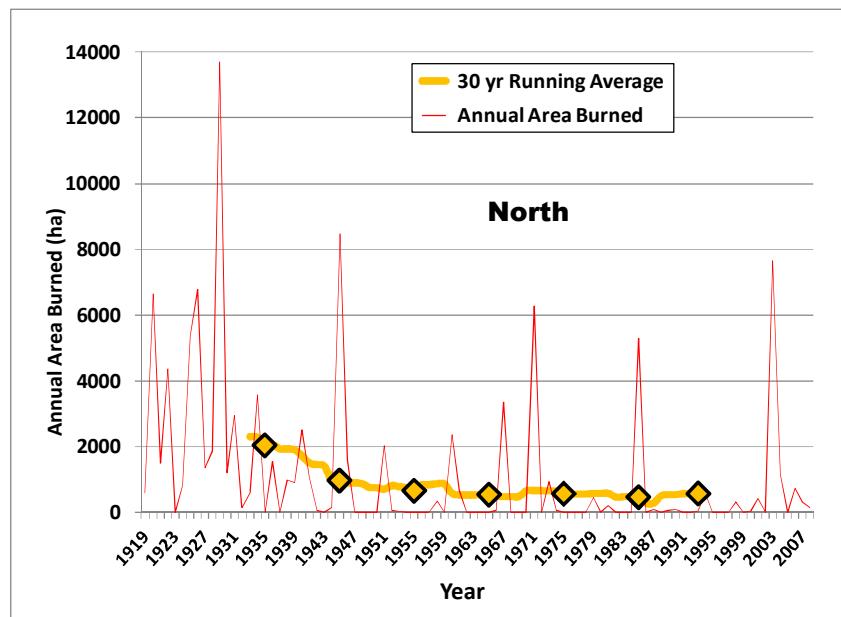
Additional bioclimate modeling of common tree species' ranges also projects shifts in individual trees species envelopes that are consistent with the projected changes in ecosystem envelopes. Drought resistant and fire tolerant low elevation species' envelopes tend to expand and shift to the north and upslope. Changes in bioclimate envelopes for species currently occurring at upper elevations generally indicate a decrease in occurrence for those species.

### 3.2.2 Fire Impacts

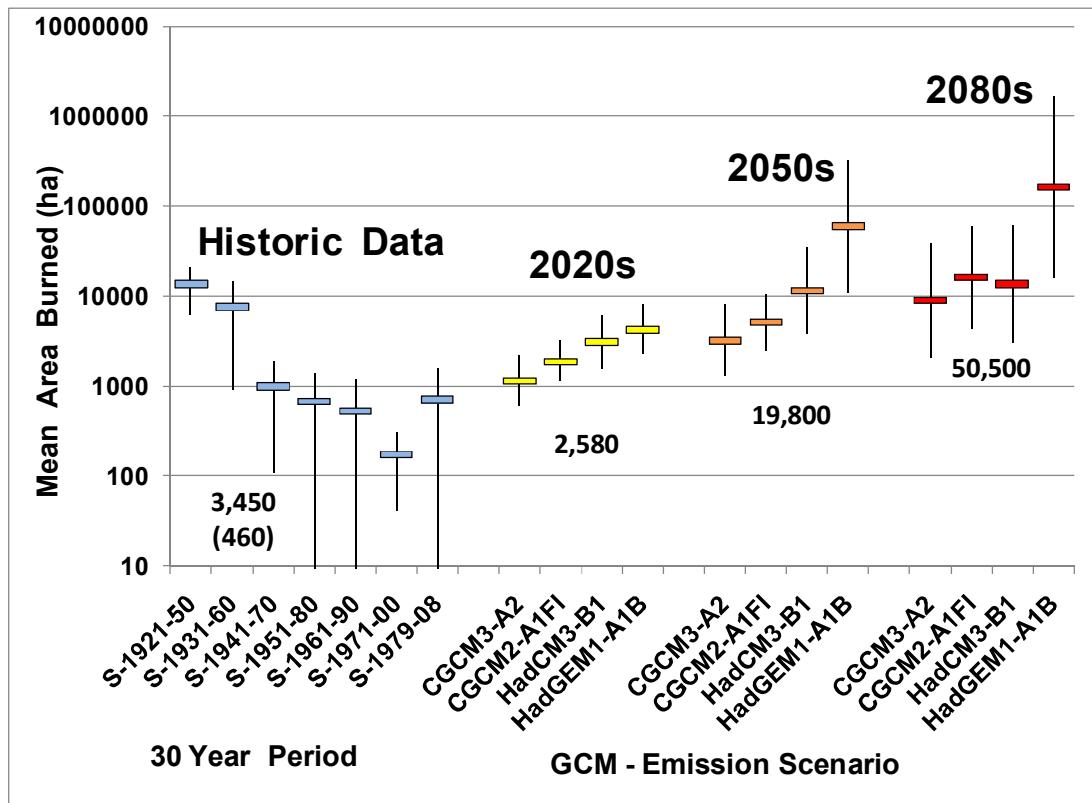
To investigate how the occurrence of fires may change with various climate change projections, we employed regression analysis to identify climatic variables that were predictors of area burned in the past, and then used climate change projections of those variables to estimate future changes in area burned (see Report #4, Utzig et al. 2012 for full results).

The analysis used a digital database of fires from 1919–2008 for the West Kootenay study area as a data source for past fires (Taylor and Thandi 2003). Future climate projections were derived from four GCM/ emission scenario combinations. A review of literature on the relationship between fire and climate in British Columbia and the Pacific Northwest identified a number of potential climatic variables for the analysis including variables such as mean monthly maximum spring and summer temperatures, previous winter snowfall, moisture deficit<sub>1</sub>, spring and summer monthly precipitation, and previous summer precipitation. A multiple regression analysis was performed where these predictors were used to estimate annual area burned for each of the subregions. All of the potential predictors were tested individually and in combination, until the most supported model was created for each subregion. Each model was further evaluated for fit, and then run for projected future values of the predictors to estimate future area burned.

The area burned in each of the subregions was highly variable from year-to-year, including many years with no fires being recorded, and a few years with extensive burned areas (see Figure 8). As expected, over the past ninety years the average annual percentage of area burned was most in the South and least in the North, with the Mid Subregion intermediate. The annual percentage of area burned in the early portion of the 20<sup>th</sup> century was much greater than the long term average, while the annual percentage for latter part of the century was much less than the long term average, which are consistent with other regional studies for the US Rocky Mountains (e.g., Morgan et al. 2008, Littell et al. 2009, Westerling et al. 2006). Climate has also changed over this period – and regression analysis of climatic factors with area burned explains a major portion of the decreasing trend, although fire suppression efforts and changes in ignition sources also have likely contributed to the changes.



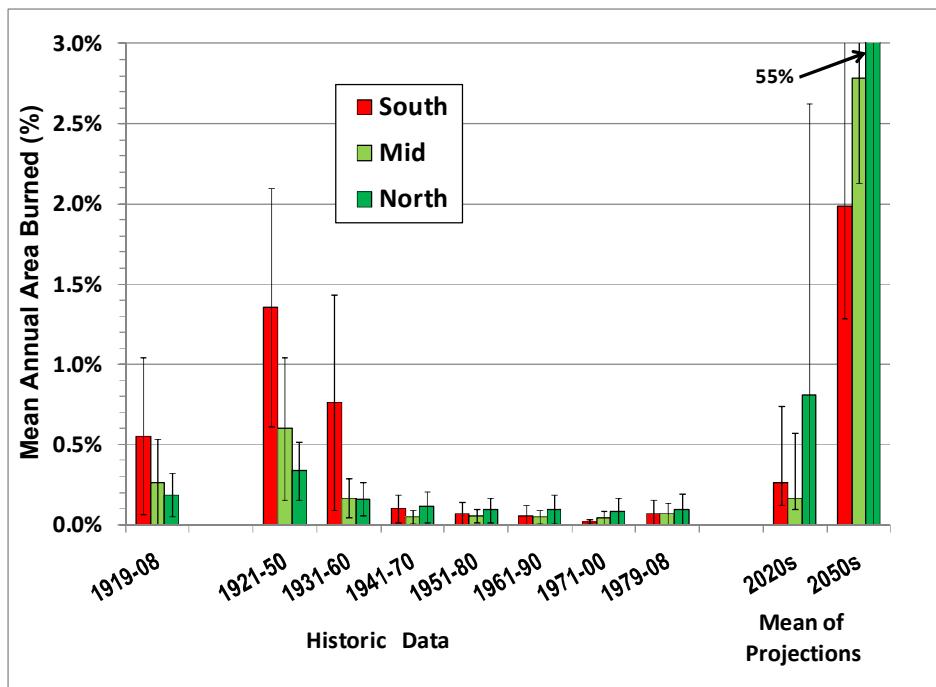
**Figure 8. Historical annual area burned for the North Subregion (red line). Orange line is running 30-year mean of annual area burned (black diamonds 30-year means utilized in the subsequent graphs).**



**Figure 9.** South subregion historic 30 year means (blue boxes) and regression projections (yellow, orange and red boxes) of area burned (with 95% confidence intervals). Values below the historic whisker plots are a mean of the 1921-2008 area burned, and in parentheses the mean of 1951-2000. Values below the projection plots are mean area burned of the GCM/ emission scenarios for each time period. CIs for the projections do not include uncertainty from the GCMs. Note log scale on graph.

The primary predictor variables for each subregion were used to estimate the range of area burning into the future, based on scenarios of future climate. The results of the regression models are only shown for the South subregion (see Figure 9). The results for the Mid and North are available in Report #4, Utzig et al. 2012. The wide and skewed confidence intervals (CIs) of the historic data reflect the high year-to-year variability in annual area burned, and the high frequency of years with no area burned. The CIs in the projected data reflect the uncertainty in the regression model, but they do not include the uncertainty in the GCMs or the emission scenarios, nor the uncertainty in the assumption that future year-to-year variability will be similar to past variability, and possible changes in the relationship between climate and area burned. The projected mean area burned as a percentage of total area for the 2020s and 2050s is shown in Figure 10.

Slightly different climatic factors were found to be significant in the three subregions of the study area, but with maximum temperature in the hottest month to be significant in all regions. The regression models for all three subregions project steadily increasing area burned in all three subregions for all GCM/ scenario combinations, although there is substantial uncertainty regarding the magnitude of the increases. The greatest projected increases were in the North – the mean projected increase (across all models) shows an increase of almost 300 times for the North, 30 times for the Mid and 15 times for the South Subregion by the 2050s, with minimum increases of at least 3 or 4 times by then.



**Figure 10. Mean area burned projections as a percentage of total area in comparison to area burned in historic 30-year periods (2020's = 2011-2040 and 2050s = 2041-2070).**

The West Kootenays is a diverse area – ranging from rolling topography and dry open forests in the lower elevations of the South, to steep sided valleys and wet interior cedar hemlock ‘rainforest’ in the North. This starting point clearly influences how changes in climate will affect future fire – with relatively little fire in the North historically, but with a high potential for drying and warming to increase this level. The increased importance of spring climatic variables in the North found in the regression analysis, is likely a reflection of the increased importance of spring snowmelt and its potential affect on the fire season in that high snowfall subregion. Early snowmelt can facilitate fires by increasing the length of the fire season and increasing fuel drying that leads to the build up of maximum drought codes. In contrast, in the South and Mid areas, summer high temperatures and drought seem to be the main factors. The projected changes in climatic variables correlated with area burned in the North appear to be changing at a faster rate than those in the South, leading to a steeper increase in estimated area burned. Available fuel will likely become a limiting factor before some of the area burned projections will be achieved, especially in the North subregion.

There are many implications associated with the results found here – increased risk of fire for the whole region will affect all values currently available from our forests – timber, water supplies, biodiversity and rural living to name a few. The implications for fire management are especially concerning. Recent modeling in Ontario (Podur and Wotton 2010) has similarly projected an eightfold increase in area burned by the end of the 21<sup>st</sup> century for that area – in part due to increased fire frequency potentially overwhelming fire suppression resources. There will be significant implications for forest management in general, including silvicultural systems, retention levels and selection of species to plant.

### 3.2.3 Insects and Disease

Climate change can affect forest health in many ways, some positive and some negative. There can be direct effects on insect and disease populations: for example, warmer temperatures may reduce time required for insects to complete life cycles, warmer winters may result in higher insect overwintering survival therefore higher brood

success, or larval desiccation may occur with higher temperatures. Indirect effects also occur: for example, summer drought conditions can stress trees, thereby increasing susceptibility to a wider range of insects and diseases.

Complex mechanisms of change can be expected, making prediction of effects difficult. For example, warming temperatures affect tree phenology altering the host-pest relationship, as has been predicted for spruce budworm where bud break is desynchronized from defoliator larval emergence(Johnstone et al. 2009). Increased precipitation can alter humidity affecting spore release for some diseases (Kliejunas et al. 2009). Extreme weather events (which are expected to increase) can affect stand susceptibility, - for example wind storms may create extensive windfall increasing bark beetle susceptibility.

Climate change can also cause range extension or retraction of insects, disease agents or hosts. As tree species ranges change, insects and diseases can follow into new areas or be left behind, or trees can encounter new insects and diseases as trees and insects and diseases move into new areas. In general, it is expected that a warmer climate will increase diversity of insects at higher elevations (Woods et al. 2010). The effect on tree populations can be difficult to quantify as tree vigour may increase or decrease with the same climate change, thereby increasing or decreasing the susceptibility to attack.

A summary of the projected climate-related changes to risk from insects and pathogens is provided below, and more detailed information is provided in Report #6 (Pinnell 2012), organized by regionally important tree species and by maturity class.

### **3.2.3.1     Insects – Summary of Projected Changes**

- As insects are primarily influenced by temperature regimes, increases in regional temperature will likely change distribution, frequency and severity of population outbreaks.
- Insects have short life spans and therefore can adapt to climate change much faster than the host species.
- Potential shifts in timing of critical life stages could lead to increased or decreased insect levels (Logan et al. 2003).
- Douglas-fir beetle, western balsam beetle, spruce beetle, western hemlock looper and spruce leader weevil commonly occur and are considered important insects that may be affected by climate change (Abbott et al. 2007).
- Northern and high elevation forests are expected to experience most change due to anticipated increases in temperature (Logan et al. 2003).

### **3.2.3.2     Pathogens - Summary of Projected Changes**

- Pathogen levels are generally more influenced by precipitation as compared to temperature (Woods et al. 2010). Note however that changes in precipitation regimes are more difficult to predict than changes in temperature regimes; changes in pathogen levels are therefore also difficult to predict.
- Increases in temperature will allow expansion up in latitude and elevation.
- Overwinter survival will likely increase with increases in temperatures.
- Warmer night temperatures are conducive to increased spread of diseases.
- Host vigour is an important factor for pathogen susceptibility. Increased carbon dioxide levels have been linked to increased tree growth and reduced susceptibility (Sturrock et al. 2011).

In addition, different effects are expected for different seral stages:

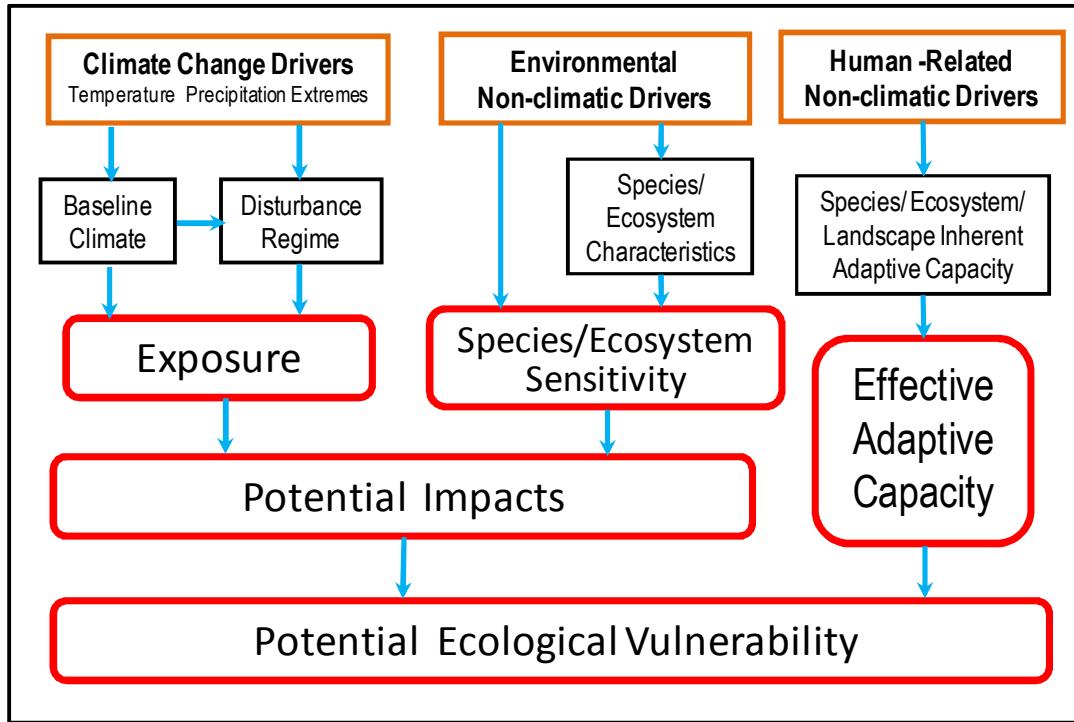
- Mature and old forests: Outbreaks of Douglas-fir beetle, western balsam beetle, spruce beetle and western hemlock looper have regularly occurred in mature West Kootenay forests. Evidence suggests that climate change may contribute to increased risk of outbreak of these insects in the short to medium term.
- Existing regeneration and young stands: Forest insect and disease surveys indicate there are many insects and diseases affecting growth and causing mortality in young stands. Spruce leader weevil, white pine blister rust, other stem rusts in lodgepole pine, foliar diseases of lodgepole pine and larch and Armillaria root disease are routinely encountered in plantations. Lodgepole pine plantations appear to be at risk to a wider range of insects and diseases. Overall, climate change is predicted to increase incidence of most of these damaging agents.
- New regeneration: Future regeneration is also subject to attack by insects and diseases found in existing plantations. In addition, as climate changes in the short to mid-term it is possible that new insects and diseases that have only occurred in low numbers may reach outbreak levels in future plantations. These may include insects and diseases that are triggered by drought conditions such as western false hemlock looper. In addition, certain diseases that in the past have only caused growth loss may now contribute to mortality as observed with larch needle cast and dothistroma. Awareness of common and unusual forest health concerns in nearby existing plantations provides valuable guidance when planning future plantations.

The uncertainty associated with climate change and its potential impacts to forest health requires forest managers to plan future forests with maximum flexibility to respond to changing conditions. It is important to keep in mind when evaluating climate change impacts to forest health that it is only one variable affecting insect and disease trends. Management practices such as silvicultural system selection (i.e., even- versus uneven-aged management), planting stock genetics (e.g., monocultures), species diversity in planting stock, and stand tending practices (e.g., species selection during spacing) also affect insect and disease risk. Ongoing forest health surveys should provide data on insect and pathogen occurrences in intermediate, mature and old stands, while free-to-grow surveys should provide information in regeneration and young stands. Annual monitoring of survey results will be required to track unusual occurrences, and identify climate change-related outbreaks as quickly as possible, so that appropriate management strategies can be developed.

## **4.0 ECOSYSTEM VULNERABILITY ASSESSMENT**

The framework employed in our assessment is based on that outlined by Fussel and Klein (2006), but modified to be more applicable to assessing ecosystems rather than social systems (see Figure 11). Our assessment is initiated by identifying and examining the key drivers for the ecosystems present in the study area. We have grouped these in three broad classes: non-climatic environmental drivers, human-related drivers (i.e. development pressures/threats) and climate change-related drivers. The climate change and other environmental drivers in turn influence the two key components that determine the potential impacts: exposure and sensitivity. Vulnerability to those potential impacts is then moderated by the ecosystem's adaptive capacity. In this case we estimate an ecosystem's "inherent" adaptive capacity, and consider whether that has been enhanced or degraded by past and ongoing human-related activities, and then assign the ecosystem a resulting "effective" adaptive capacity.

In contrast to many climate change vulnerability assessments, we have chosen to focus on the "ecological system," specifically forest ecosystems, rather than the "social ecological system" or the "social system". In forest-dependent social ecological systems, forest ecosystems are the basis for the goods and services that support the social systems, and therefore are one of the key components to understanding the potential impacts and vulnerabilities of the full social ecological system. Our discussion of the social system is limited to examining potential adaptation measures that may be taken by forest managers and practitioners to moderate potential adverse affects (Report # 9, Holt et al. 2012), and the identification of opportunities and barriers for implementing adaptation measures (Report #8, Pearce 2012).



**Figure 11.** Framework for assessing the vulnerability of West Kootenay ecosystems. Orange boxes are groups of drivers, black boxes are existing conditions, red boxes are outcomes of the analysis (adapted from Fussel and Klein 2006 and Klausmayer et al. 2011).

The approach for rating each of the components of the vulnerability assessment are described below, and summarized in Table 2. **The ratings for each of the components are relative between assessment units within the West Kootenay study area, they are not absolute ratings that can be compared to ratings of areas outside the study area.** The unit of study for the ecosystem Vulnerability Assessment are the ‘Regional Landscapes’ as described in Section 2.2 of this report, and in more detail in Report #7 (Utzig and Holt 2012).

Due to the uncertainty associated with climate change projections, we assessed exposure for three different scenarios: warm/ moist (HadCM3\_B1), hot/ wet (CGCM3\_A2) and very hot/dry (HadGEM\_A1B). These illustrative scenarios provide a reasonable representation of the range of the various scenarios produced by the IPCC.

## 4.1 Vulnerability Approach

As outlined in Figure 11, potential impacts result from a combination of exposure and sensitivity. Potential impacts then combine with adaptive capacity to result in vulnerability. A brief description of each of these terms is provided below, and the assessment criteria for each are summarized in Table 2.

**Exposure:** We chose to focus on changes in seasonal climatic variables and changes in disturbance regime since our examination of drivers with forest practitioners found those two drivers to be some of the significant determinants for the character of local ecosystems, and they are both closely linked with potential climate change.

**Sensitivity:** Our evaluation of the sensitivity of ecosystems to changes in climate and associated changes to disturbance regimes focussed on attributes of the ecosystems currently occupying the assessment unit, including dominant tree species and basic ecological processes and functions. We considered factors such as the contrast between the current disturbance regime and projected disturbance regimes, suitability of current tree species for

projected climates. One key factor was what has been termed “functional-response diversity” by Folke et al. (2004) – an example being the presence or absence of fire tolerant species that can potentially cope with increases in fire frequency. We recognize that many other factors affect the potential sensitivity of ecosystem or components of ecosystems (e.g., presence of keystone or foundation species) but due to the scale of our assessment we did not attempt to include more detailed assessment of species level sensitivity in this first phase of analysis.

**Potential Impacts:** The assessment combines elements of exposure and sensitivity to estimate “potential impacts.” In addition to exposure and sensitivity, our assessment of potential impacts also considered the results from our analyses of projected bioclimate envelope shifts. We have summarized the potential impacts by summarizing the projected bioclimate envelope shifts for the three climate scenarios described above, for each assessment unit. We have designated these “potential” impacts because of the level of the uncertainty in the projections of climate change and the associated impacts, but also because they potentially can be modified by future adaptation and/or mitigation actions<sup>6</sup>.

**Adaptive Capacity of Ecosystems:** we considered two major groups of factors in assessing adaptive capacity: the “inherent” adaptive capacity of the assessment unit based on its specific characteristics, and secondly human-related activities and their associated effects on adaptive capacity. We designated the combination of these two groups of factors as “effective” adaptive capacity. Many of the factors considered relate to the ability of the ecosystem present in that location today to transition to new ecosystems under projected climate regimes. Human-related factors that contributed to the final determination of effective adaptive capacity included factors such as fragmentation due to forest harvesting, urbanization, agriculture or reservoir construction, reduced species and/or genetic diversity, pollution and modified disturbance regimes.

**Potential vulnerability:** Vulnerability has been determined by considering the potential impacts, resulting from exposure and sensitivity, and effective adaptive capacity – i.e. the magnitude and direction of change and the capacity for reducing and/or accommodating the impacts of those changes. We have provided three ratings for each assessment unit, related to the three climate scenarios described above.

In determining the vulnerability ratings, we have employed resilience theory concepts to assist in understanding the key question of “vulnerability to what?” We have defined the “what” to be a regime shift. The relative ratings of vulnerability are based on the likelihood of a regime shift, the magnitude of the shift and the manner in which the shift is hypothesized to proceed.

In general terms we consider three potential outcomes<sup>7</sup>:

- **No regime shift** – This includes the system remaining as it is today, or changing in relatively minor ways. This would include maintaining a similar natural disturbance regime and successional pathway, but may include potential changes in dominant tree species e.g., shift from wet interior cedar-hemlock [W ICH] or wet Engelmann spruce-subalpine fir [W ESSF] to coastal transition ICH or coastal western hemlock [CWH]).
- **Non-catastrophic regime shift** – This likely includes changes in natural disturbance regime, and potentially changes in successional pathways and dominant tree species. However the shift can proceed in an orderly non-disruptive manner (e.g., alpine to ESSF or ICH with gradual forest in-fill), or it can follow a disturbance event (e.g., interior Douglas-fir [IDF] forest conversion to grassland/ savanna following fire due to regeneration failure).
- **Catastrophic regime shift** – This type of change generally includes a significant change in natural disturbance regime and major shifts in dominant species. This type of shift almost always is associated with an intensive disturbance event (e.g., stand-replacing fire or epidemic insect outbreak). The

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<sup>6</sup> The emission scenario (B1) utilized in the Hot/ Moist climate scenario assumes short- to medium-term reductions of greenhouse gas emissions, which may include some mitigation measures.

<sup>7</sup> In describing the estimated likelihood of catastrophic regime shifts, we have used IPCC (2012) likelihood ratings.

distinguishing factor is that the shift is disruptive and disorderly. Rather than shifting to a successional phase leading into renewal, the system may move into a 'stalled' or 'chaotic' phase, from which it could take a long period of time to recover (or may be irreversible). This is potentially more likely in areas where the magnitude of change is greater, the current ecosystems have limited diversity, and in areas where ecosystems have infrequent stand-replacing disturbances, allowing persistent ecosystems to essentially become relics of previous climatic conditions. Other contributing factors may include a lack of seed source for suitable species, or competition by early successional and/or invasive species that arrest succession. The occurrence of a high severity stand-replacing fire in an old growth stand of Wet ICH, followed by a few years of hot dry summers could be an example of such an event. These types of stands currently are driven by gap-replacement disturbance regimes with extremely low occurrence of drought tolerant seral species, hence the likelihood of a prolonged chaotic recovery – or a possible regime shift to non-forested brush. These types of regime shifts are the most likely to result in significant and long-term interruptions in ecosystem goods and services (Folke et al. 2004, Chapin et al. 2009).

**Table 2. Summary of key assessment criteria for each component of the assessment.**

Exposure	Sensitivity	Effective Adaptive Capacity	Potential Vulnerability
Projected temperature and precipitation changes	Current disturbance regime Diversity of tree species	Local and downslope tree species seed sources	Collective ratings of exposure, sensitivity and effective adaptive capacity
Projected increase in extreme weather events	Presence of fire tolerant spp. where relevant	Potential for species shifts from down-slope	Likelihood and severity of regime shift
Severity of projected climate-related changes in disturbance regimes <sup>8</sup>	Fuel loading where increased fire was a consideration	Natural connectivity Soil capability Degree of human-caused fragmentation/ disturbance	Degree of uncertainty (range of possible outcomes)

## 4.2 Summary of results

Table 3 provides a summary of potential impacts and relative ratings of exposure, sensitivity, effective adaptive capacity and potential vulnerability for each assessment unit. The ratings are primarily based on project team expert opinion and the criteria in Table 2. The potential impacts include information on the currently mapped general ecosystems and the general ecosystem bioclimate envelopes projected by the three climate scenarios. The final two columns provide information on the key contributing factors to the ratings, as well information related to the potential for a regime shift, and which type of regime shift.

The assessment ratings include: Very High, High, Moderate, Low and Very Low (VH, H, M, L and VL). Assessment units rated VH or VL are considered the highest and lowest rated assessment units in the study area, compared to all the other assessment units in the study area. ***The ratings are relative between assessment units within the West Kootenay – they are NOT absolute ratings that can be compared to ratings of areas outside the study area.***

<sup>8</sup> NDT = Natural Disturbance Types, 1 = rare stand initiating events; 2 = infrequent stand initiating events; 3 = frequent stand initiating events 4 = frequent stand-maintaining fires; 5 = alpine and subalpine environments; changes from NDT 1 to 2 were considered moderate, 1 to 3 or 4 and 2 to 4 severe; from 3 to 4 moderate; and 5 to 2,3 or 4 low; estimated severity often varied between scenarios; for more information see: <http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/biodiv/biotoc.htm>

## **4.3 Discussion**

The low elevation assessment unit in the North Subregion, currently dominated by Moist and Wet ICH is highlighted as one of the most vulnerable systems (High to Very High) in the West Kootenays. These systems are predominantly NDT1 – gap dynamic dominated – forested ecosystems that are projected (by both bioclimate shifts and fire dynamics) to potentially become NDT 3 / 4 - frequent fire dominated systems. This shift, combined with the general lack or minor occurrence of fire adapted species through much of the unit (e.g., Ponderosa pine, lodgepole pine, Douglas-fir, western larch) has the potential to result in a change in pathway during the renewal phase of the adaptive cycle (e.g., after a stand-replacing disturbance event). In addition, the original pathway (successional development of a forested ecosystem) may become ‘arrested’ or ‘chaotic’ or ‘stalled’, so slowing the new pathway of sequestration of resources and regrowth. This leaves the ecosystems not only potentially failing to provide the wide array of goods and services humans are currently adapted to, but may also result in the system moving into a state that is irreversible (or only slowly reversible), for example being shrub-dominated or invasive species dominated.

Although the assessment unit at low elevation in the South Subregion – currently a mix of NDT 3 and 4, with moderate and high frequency and short fire return intervals – is projected to shift to hotter drier climates, with all three scenarios projecting shifts to NDT 4 grassland/ savanna bioclimate envelopes for a significant portion of the area, the vulnerability ratings are all Low and Medium – despite significant human-related impairment of adaptive capacity. Although the shift from forest and open forest to grassland and savanna is a major structural change, many of the dominant species currently occupying the projected envelopes are already present on drier sites in the assessment unit. Therefore in spite of the significant changes projected, we have rated these systems less vulnerable overall, because the natural disturbance type and ecosystem development pathway remains similar. We expect these systems to be less likely to move into a ‘stall’ or ‘chaotic state’ or ‘arrested’ state, although there is significant risk that invasive species could colonize sites after a disturbance event, so preventing a typical return to a more productive successional pathway.

In the Mid Subregion, the mid elevation bands are given similar ratings to the wetter ecosystems in the North (High or Very High vulnerability), because of the similar predicted regime shift. The lower and highest elevation bands of the Mid are given lower vulnerabilities since the change in natural disturbance regime is less likely to result in a catastrophic regime shift.

The use of three climate scenarios has resulted in three sets of impact and vulnerability ratings. This range can be used to get some understanding of the potential range of futures that could be expected. Where it is more clear (though by no means certain) in what direction the system is headed then it becomes easier to translate into management adaptation direction. Where the three scenarios result in quite different potential outcomes it makes translation into management direction more difficult, with the need to concentrate on robust options, rather than optimal options.

**Table 3. Potential impacts and relative ratings of exposure, sensitivity, effective adaptive capacity and potential vulnerability for study area assessment units, including comments on contributing factors and potential regime shifts.**

Assm't Unit	Exposure	Sensitivity	Potential Impacts <sup>9</sup>	Effective Adaptive Capacity	Potential Vulnerability	Comments	
						Key Contributing Factors <sup>10</sup>	Regime Shift (RS)
North <1000m	H-M-H	M	From M/W ICH to PP and/or GF/ MSD and/or GS	L	VH-H-VH	Magnitude and direction of NDT shift (2/1 to 4/3), lack of local seed source for fire-resistant tree spp., fragmentation by reservoirs and harvesting, no downslope seed source availability	RS very likely; likely catastrophic
North 1000-1500m	M-H-VH	VH	From M/W ICH/ W ESSF to D/M/W ICH and/or Ctran/ MSD and/or PP/ GS	M	M-M-VH	Uncertainty of exposure/ impacts and possible magnitude of NDT shift (1/2 to 2/3 or 4), lack of local seed source for fire-resistant tree spp., moderate fragmentation	RS likely to very likely; likely to be catastrophic
North 1500-2000m	VL-VL-VH	VH	From W ESSF/ Atran to W ICH/ and/or CWH/Alp and/or PP/ D ICH	M	L-L-VH	Possible magnitude of NDT shift (1/5 to 1/5 or 4/3), no local seed source for fire-resistant tree spp., minimal fragmentation	RS unlikely, but if so, likely catastrophic
North >2000m	L-VL-M	M	From Atran/ Alp to W ICH/ W ESSF and/or Alp/ Atran and/or D/W ICH/ D ESSF	L	L-VL-L	Limited magnitude and direction of NDT shift (5 to 1 or 5 or 3/2), tree spp. seed source downslope, natural fragmentation	RS about as likely as not; very unlikely to be catastrophic
Mid <1000m	M-L-M	L	From D/M ICH to PP/ GS and/or GF/ MSD	L	M-M-M	Moderate NDT shift (3/2 to 4/3 or 4), some local fire resistant tree spp. seed sources, extensive fragmentation, no downslope seed source availability	RS likely; unlikely to be catastrophic, significant invasive spp. risk
Mid 1000-1500m	H-H-VH	M	From M ICH/ W ESSF to PP/ D ICH and/or MSD/ GF/ Ctran and/or GS/ PP	H	H-H-VH	Magnitude and direction of NDT shift (2/1 to 3/4 or 4), some local and downslope seed sources, limited fragmentation	RS likely to very likely; about as likely as not to be catastrophic

<sup>9</sup> See App. 2 for generalized ecosystem types; for more detail on the projected impacts see Report # 5 (Utzig 2012b).

<sup>10</sup> NDT = Natural Disturbance Types, 1 = rare stand initiating events; 2 = infrequent stand initiating events; 3 = frequent stand initiating events 4 = frequent stand-maintaining fires; 5 = alpine and subalpine environments; changes from NDT 1 to 2 were considered moderate, 1 to 3 or 4 and 2 to 4 severe; from 3 to 4 moderate; and 5 to 2,3 or 4 low; estimated severity often varied between scenarios; for more information see: <http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/biodiv/biotoc.htm>

Assm't Unit	Exposure	Sensitivity	Potential Impacts <sup>9</sup>	Effective Adaptive Capacity	Potential Vulnerability	Comments	
						Key Contributing Factors <sup>10</sup>	Regime Shift (RS)
<b>Mid 1500-2000m</b>	H-M-VH	VH	From W ESSF to D/M/W ICH and/or Ctran/ MSD and/or PP	M	H-H-VH	Uncertainty of exposure/ impacts and possible magnitude of NDT shift (1 to 2-3-4), lack of local tree spp. seed source, some but available downslope, limited fragmentation	RS likely to very likely, likely to be catastrophic
<b>Mid &gt;2000m</b>	L-L-M	M	From Atran/ Alp to W ICH and/or Ctran/ Alp and/or PP/ D ICH/ D ESSF	L	L-VL-M	Limited magnitude and direction of NDT shift (5 to 5 or 3/4), downslope seed sources, natural fragmentation	RS about as likely as not; very unlikely to be catastrophic
<b>South &lt;1000m</b>	M-L-M	VL	From D ICH/ GF to GS/ PP/ GF	VL	L-L-M	Limited magnitude of NDT shift (3/4 to 4/3), local seed source for tree spp., extensive fragmentation, no downslope seed source availability	RS likely to very likely (localized); unlikely to be catastrophic, high invasive spp. risk
<b>South 1000-1500m</b>	L-VL-H	VL	From D/M ICH to PP/D ICH and/or GF/ MSD/ D IDF and/or GS	VH	VL-VL-H	Limited magnitude of NDT shift (3/2 to 3/4), local and downslope seed source for tree spp., moderate fragmentation,	RS about as likely as not; about as likely as not to be catastrophic
<b>South 1500-2000m</b>	M-M-H	M-H	From D/W ESSF to D/W ICH and/or Ctran/ MSD and/or D/W IDF/ PP/ GS	M	L-L-M	Limited magnitude of NDT shift (3/1 to 3/2 or 3), downslope seed source for tree spp., low fragmentation	RS unlikely, but if so, about as likely as not to be catastrophic (localized risk)
<b>South &gt;2000m</b>	L-L-M	L	From D/W ESSF/ Atran to W ICH and/or Ctran and/or D ICH/ W IDF/ PP	L	VL-VL-L	Limited magnitude of NDT shift (3/1/5 to 2/3), downslope seed sources, natural fragmentation	RS likely; very unlikely to be catastrophic

In terms of consistency of the projections from the three scenarios, the low elevation in the North Subregion and mid elevation in the Mid Subregion are most consistent – and predicted to have the highest vulnerabilities. Alternatively, the highest elevation bands in the South, North and to a slightly lesser extent the Mid, have consistently Low and Very Low vulnerability ratings. In theory then, at least this information provides managers with consistent predictions on what the future may have in store, and can potentially use this information to set priorities. Alternatively, the mid elevation band in the North which has Low, Low and Very High vulnerability ratings – depending on scenario, and the South mid elevation band has ratings of Very Low, Very Low and High ratings, resulting in significant uncertainty about potential outcomes. For these systems, choosing ecologically appropriate adaptation strategies will be particularly challenging. In addition, all three scenarios demonstrate the possibility of novel or non-analogue climate envelopes, which will add additional challenges for managers.

The concepts of resilience, multiple stable states and thresholds appear to be useful in understanding, or at least developing a theoretical framework for understanding the potential dynamics of West Kootenay ecosystems. Looking for and understanding potential feedback loops appears critical – since critical thresholds are those that, once crossed, propel the system through a state where feedback moves the system quickly into new dynamics and potentially then regime shift. Systems with positive feedback loops – events that build upon one another – causing a cascade of responses will tend to react suddenly and dramatically. Further discussion of how our results fit within the resilience literature is provided in Report # 7.

## **5.0 ADAPTATION OPTIONS**

Developing effective adaptation actions for climate change is the ultimate goal of the FFESC, and this project is a first step along that path for the West Kootenays. Different components of the project were designed to be fit together in order to build a strong foundation for climate change adaptation in this region. Effective adaptation relies on many different elements coming together, including developing an understanding and willingness from many levels of individuals to ‘want’ to adapt, understanding the vulnerabilities and risks associated with potential climate futures, developing practical strategies around ‘what to do’ under a range of scenarios, and creating incentives, or removing barriers in order to make it happen. This process is treated in more detail in our Report # 9, (Pinnell et al. 2012).

Since the process of identifying specific adaptation actions is a very complex one, and larger than the timeframe available in this project, in the adaptation actions report we:

- identify a series of general principles, or factors to consider while developing adaptation actions;
- outline a decision-making process for moving ahead;
- use the results from the ecosystem vulnerability assessment developed in this project (Report #7, Utzig and Holt 2012) as a basis for identifying potential adaptation actions at three scales of planning (strategic or planning scale, ecosystem or stand scale, and operational scale; and,
- recognise that actual adaptation actions needs to consider a broader range of issues than simply ecosystem vulnerability.

### **5.1 How to approach the problem**

Adapting to climate change is complex, and has therefore been termed a “wicked” and even “super-wicked” (Levin et al. 2009). The following provides an overview of some key factors to include in approaching the problem:

### **5.1.1 Changing the framework**

At this stage in the development of options, few (if any) forest management adaptation initiatives have advanced through the steps of evaluating adaptation options, deciding on the best options, implementing these options, and learning through monitoring. Consequently the current advice regarding selecting adaptation options provides principles for approaching this task. A number of sources have provided succinct advice on the topic (Petersen et al. 2011; UKCIP<sup>11</sup>; Harford 2008), and some of their key points are summarized below:

- **Promote resistance to climate change**—This strategy includes actions and treatments that enhance the ability of species, ecosystems, or environments, social systems to resist forces of climate change, and to maintain values and ecosystem services in their present or desired rates and conditions.
- **Develop resilience to climate change**—As discussed in Report #2 (Holt and Pearce 2012) in a climate change context, resilience refers to the capacity of a system or environment to withstand or absorb increasing impact without changing state.
- **Assist response to climate change**—The most proactive strategic actions are those that work directly with the changes that climate change is creating; that is, they assist transitions to future states by moderating and minimizing undesired and disruptive outcomes.
- **Realign highly disturbed ecosystems**—When ecosystems have been disturbed beyond historical ranges of natural variability, restoration can be implemented to return structure, composition, process, and ecosystem services to historical states. This approach makes sense where disruption has been severe, and projected climate changes are within the historical climatic range, however if climate change is outside the historical range, assisting the transition to a future state may be more appropriate.

Adjust social expectations and think mid to long term:

- **Accept the impacts, and bear the losses** that result from climate risks (e.g. increasing loss estimates from wildfires, insects and diseases in allowable annual cut decisions).
- **Off-setting losses by sharing or spreading the risks or losses** (e.g. through insurance or reallocating operating areas in a management unit after a large wildfire).
- **Avoiding or reducing exposure to climate risks** (e.g. harvesting climate sensitive stands, building roads to higher peak flow standards).

Change the framework:

- **Identify robust actions (especially important where there is significant uncertainty).**
- **Promote smart adaptation:** through knowledge mobilization and outreach – including understanding the economic implications of ‘not adapting’.
- **Mainstream:** adapt existing mechanisms of change, and incorporate climate change as central feature.
- **Build or foster development of the right tools:** create tools and practices that lead to effective adaptation.
- **Build Expertise:** increase existing capacity and develop capacity within organizations to be more aware of, and technically capable of adapting to, climate change information and implications.

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<sup>11</sup> See <http://www.ukcip.org.uk/wizard/wizard-4/4-1/>

### **5.1.2 Consider uncertainties**

Considering uncertainties is a key part of any management strategy. There are a vast number of uncertainties that climate change brings to the forest management realm. We discuss one aspect of these uncertainties below – which climate future am I managing towards?

In an attempt to start to deal with the range of potential futures, we used the three recommended climate scenarios (Murdock and Spittlehouse 2011) in the ecosystem vulnerability assessment, which then resulted in three sets of impact and vulnerability ratings. This range can be used to get some understanding of the potential range of futures that could be expected. Where the three scenarios agree, and it is more clear (though by no means certain) in what direction the ecosystems are headed then it becomes easier to translate into management adaptation direction. Where the three scenarios result in quite different potential outcomes, it makes translation into management direction more difficult, creating an even further increased need to concentrate on robust options, rather than optimal options.

The general principles laid out above can help focus management strategies – by looking at ways to promote resilience across the range of potential futures. However, the time, effort and information required to fully develop this process should not be under-estimated.

### **5.1.3 When to act?**

Climate change is ongoing today, but the specific impacts of the changes in climate can occur in the short-, mid- or long-term – often in some complex probabilistic manner. Considering when to act will be a critical part of an effective adaptation plan. Factors to consider include:

- the urgency for action – based on both key risks and vulnerabilities;
- the possibility of resistance – is a resistance strategy warranted (in relation to existing values or increasing the possibility of local adaptation), and is it likely to be effective; and,
- opportunity for success – only a certain subset of the problems generated by climate change will be effectively altered by management practices or strategies; determining which actions are likely to be most effective and at what scale will be an important part of the decision-making process.

## **5.2 What to do?**

Using the ecological vulnerability assessment ratings as the basis, we identify a suite of potential adaptation actions that could be applicable generally across the region, and also more specifically to the North, Mid and South subregions. We organize potential changes needed at three different scales – landscape/ planning, ecosystem/ stand, and operational scales.

### **5.2.1 Adaptation Issues by Subregion**

We have not attempted to summarize the full set of potential actions in this summary report – see Report #9 (Pinnell et al. 2012). Some of the specific issues that should be addressed in each subregion are summarized below:

North Subregion:

- significant ecosystem shifts projected – including both extensive mortality through disturbances, and decline syndrome type mortality, particularly at low elevation and on drier/ warmer sites;

- fragmentation below 1500m – harvesting, reservoirs, agriculture and settlement have fragmented elevations <1500m;
- lack of seed source for fire adapted species;
- mountainous terrain limits lateral connectivity/ movement; and,
- driest sites (low elevation/ warm aspects) and interface areas require attention first.

Mid Subregion

- significant ecosystem shifts projected – including both extensive mortality through disturbances, and decline syndrome type mortality, particularly at low/ mid elevation;
- fragmentation below 1000m – harvesting, reservoirs, agriculture and settlement have fragmented elevations <1000m;
- lack of downslope seed sources for elevations: <1000m and dry areas at 1500-2000m;
- risk of invasive plants at low/mid elevations (<1500m);
- mountainous terrain limits lateral connectivity/movement; and,
- coarse soils limit upward movement at mid to high elevations (>2000m).

South Subregion:

- significant tree mortality predicted (primarily through decline syndromes?);
- extensive fragmentation below 1000m – harvesting, reservoirs, agriculture and settlement have severely fragmented lower elevations; moderate to high fragmentation at mid elevations due to harvesting;
- lack of downslope seed sources for elevations <1000m;
- high risk of invasive plants at low/mid elev (<1500m);
- fragmentation limits lateral species shifts at >1500m; Kootenay Lake and Arrow Reservoir limit lateral and northerly species shifts at low elevations; and,
- coarse soils limit upward movement at mid to high elevations (>2000m).

## **5.2.2 Adaptation actions applicable to all subregions**

As an example of the types of direction present in Report #9, the section below provides a list of the adaptation actions that apply to all (most) elevations across all subregions.

Silvicultural systems:

- Select systems to maximize vigour and decrease susceptibility to insects and disease over the long-term.
- Increase partial cutting (shade in dry areas, structural diversity to discourage certain insects/diseases, wildlife habitat).

Stand level biodiversity:

- Increase stand structure diversity (esp. species, age classes).
- Increase retention to focus on microclimate diversity (ravines, all representative aspects, etc.); protect climate refugia
- Drier sites: increase coarse woody debris retention, increase riparian buffers for temperature sensitive streams,

- Increase wildlife tree patches to contribute to landscape connectivity

Regeneration:

- Increase diversity (esp. species, genetics).
- Assisted migration.
- Underplant with other species/ genotypes where current regen (or forest) is at risk.

Stand Tending:

- Increase growth and vigour through stand tending to reduce rotation.
- Fertilize to enhance growth, reduce rotation and improve insect/disease resistance.
- Manage species composition, density, stand structure to improve diversity and increase growth.
- Vegetation control to reduce drought stress.

Alpine management

- Monitor forest ingrowth in alpine.

### **5.3 Moving Forward**

The guidance and options presented provide a starting place for moving into action for climate change in the West Kootenays. From our interaction with forest practitioners during this project we understood that some forest practitioners in the West Kootenays are observing climate change impacts. Some of these (particularly those who attended the workshops) felt they have enough information about climate change, and are now ready to develop adaptation strategies to reduce ecosystem vulnerability. Many others do not yet see the need nor contemplate how, to adapt.

This paper offers some ideas that should be used to start the next phase of work. Immediate steps could include:

- Further development of some of the ‘planning’ adaptation actions needed, using the ideas outlined above and in Report #9.
- Use these first steps as the basis for discussion at Climate Change Conversation Forums planned by and for West Kootenay practitioners. Note the need to identify a funding and (at least one) champion to move this work forward.
- Continue to develop adaptation actions as started in this project and feed into a decision-making process and priorities can be established as to what to do where first.
- Monitoring and adaptive management must be prioritized in all areas of climate change adaptation - especially since climate change and its impacts are a complex issue with high uncertainty and significant implications for all aspects of society.

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## **6.0 BARRIERS, INCENTIVES AND OPPORTUNITIES**

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This project was primarily focused on ecological impacts, however as resources permitted it explored the human dimensions of adaptation – the legal, institutional, policy, professional practice and personal aspects of the forest management system in the West Kootenays. The concepts of socio-ecological drivers from the resilience literature, adaptive capacity from climate change adaptation vulnerability assessments and environmental psychology were explored as background for this aspect of the project.

Report # 8 (Pearce 2012) describes the socio-economic system in the West Kootenays and the concepts that were explored, then summarizes findings from a literature scan for the Canadian and BC forest management systems. This is followed by a summary of the input from the West Kootenay practitioners regarding strengths and opportunities within the system as well as the barriers and gaps from their perspective, and resulting recommendations. This preliminary research points to the need for a more significant focus on the human dimensions of adaptation to support timely, well thought out adaptations in the West Kootenay forest management system, and in BC generally.

## 6.1 Strengths and Barriers

A summary of the findings on potential strengths and barriers from that paper is presented in Table 5.

**Table 5. Summary of strengths and barriers to climate change adaptation in the West Kootenay forest management system.**

***bold = most frequently identified***

Factor	Strengths	Barriers
Local forest conditions	<ul style="list-style-type: none"> <li>Range of elevations and aspects</li> <li>Diversity of species and forest types</li> <li>Large protected areas</li> <li>Predominant public land ownership</li> </ul>	
Forest management system	<ul style="list-style-type: none"> <li><b>Relevant scientific, local and traditional knowledge made available through this project</b></li> <li>Stewardship ethics</li> <li>Certification</li> <li>Potential benefits from climate change</li> </ul>	<ul style="list-style-type: none"> <li><b>Perception of low adaptive capacity in the provincial forest management system by forest practitioners</b></li> <li>Limited funds and related operational constraints due to downsizing</li> <li>Inadequate research and innovation investment</li> <li>Inadequate knowledge exchange/extension and technology transfer</li> <li>Inadequate information management systems for monitoring and poor information about forest conditions after free-growing</li> <li>Lack of organization/corporate capital long-term planning</li> <li><b>Limited ability to mobilize resources</b></li> <li>Lack of forward looking planning and operations</li> <li>Inertia</li> </ul>
Governments	<ul style="list-style-type: none"> <li>Provincial government has some staff involved in adaptation policy development and research and has developed an adaptation action plan</li> <li>Local governments are aware of adaptation through the Columbia Basin Trust initiative</li> </ul>	<ul style="list-style-type: none"> <li><b>Out-dated provincial landscape management plans thus climate change is not included in protected areas, connectivity, biodiversity and riparian management practices</b></li> <li><b>Provincial forest management regulations and policy are inflexible, lack choice or incentives and don't account for climate adaptation, particularly those related to reforestation and free-growing</b></li> <li>Concerns about adequacy of wildfire</li> </ul>

Factor	Strengths	Barriers
		<ul style="list-style-type: none"> <li>management and interface fuel reduction</li> <li>Provincial staffing inadequate to address scope and scale of information extension, research, policy development and local solutions</li> <li>Political factors such as priorities and urban/rural power</li> </ul>
Forest management organizations	<ul style="list-style-type: none"> <li>CFs – willingness to innovate; broad objectives; long term planning; knowledge exchange/extension/tech transfer</li> <li>FLs – desire to create competitive advantage and be at the forefront; information management systems for monitoring; ability to mobilize resources</li> <li>Capacity for local sawmills to produce a range of specialty products</li> <li>Absence of a single large employer</li> <li>Capacity of facilities to withstand floods, landslides or wildfires</li> </ul>	<ul style="list-style-type: none"> <li><b>Limited financial resources due to five year economic downturn and related operational constraints</b></li> <li>Inability to influence appropriate political levels</li> </ul>
Forest practitioners	<ul style="list-style-type: none"> <li><b>Aware, concerned and recognize the urgency</b> of climate change adaptation for forest management and communities, in part through daily experience of climate change</li> <li><b>Perceive climate change as a risk</b></li> <li><b>Educated, experienced, skilled, capable and now informed</b> and ‘creating dialogue’ through this project</li> <li><b>Perception of having some capacity to adapt</b></li> <li>Willing to learn; used to change</li> <li>Adaptations included in current decisions by some</li> <li>Recognition of adaptation decisions that could be taken today (e.g. reforestation with species that are likely to be suitable over the long-term, enhanced wildfire management, increase forest diversity to strengthen resilience and monitor forest health to facilitate prompt action)</li> </ul>	<ul style="list-style-type: none"> <li><b>Lack of education, training and information available resulting in inadequate knowledge about climate change and impacts</b></li> <li><b>Lack of clarity about how to adapt including awareness/understanding of adaptation options</b></li> <li><b>Economics, government policy/regulation and knowledge identified as limiting their ability to adapt</b></li> <li>Unfamiliar with decision approaches when the future is uncertain</li> <li>Individual personalities and mindsets</li> <li>Optimism bias about future conditions by non-professional managers</li> </ul>
Public	<ul style="list-style-type: none"> <li>Support and pressure for adaptation</li> </ul>	

## 6.2 Moving Forward

There are many issues associated with moving forward and dealing with barriers and opportunities. The following sections highlight some key areas that warrant attention.

### **6.2.1 Regional time, information, research and collaboration**

- **Time and money constraints** – The down-sizing of regional government operations and the financial stress in the forest sector makes it very difficult for practitioners to prioritize non-essential tasks, which includes climate change adaptation for many practitioners. Innovative design of materials and activities is required to mainstream climate change adaptation in these conditions.
- **Compilation and accessibility of currently available literature** – The research and literature on climate change adaptation relevant to West Kootenay forest management is significant, and continues to grow. Efforts to compile and present information should be continued. Presentations to interested groups, webinars and workshops with smaller groups are other alternatives to overcome the time and resource constraints of practitioners.
- **Moving beyond early adopters** – Given the plethora of psychological barriers to climate change adaptation, the identified barrier of individual personalities and mindsets, in addition to the real time and resource limitations of local forest practitioners and managers, there are many reasons why some practitioners (e.g. BCTS, conservation organizations, managers) did not participate in the project. Non-participants should be queried to better understand their barriers and find ways they can become involved. Particular attention should be paid to senior government and industry managers, as no managers participated in the project, and practitioners rated optimism bias about future conditions as a barrier.
- **Focus now on ‘what to do’** – Making decisions about climate change adaptation is a complex process that requires more time and resources than were available in this project. The practitioners identified not knowing ‘what to do’ as one of the highest priority gaps at this stage. Continuing the information sharing, conversation forums and structured decision approaches with local practitioners is recommended to fill this gap.
- **Joint regional science-management adaptation partnership** – Climate change destabilizes much of the existing knowledge about ecosystems, challenges existing forest planning processes and creates questions about appropriate adaptation practices. Collaborative initiatives involving science and practitioners exploring regional socio-ecological systems strengthen adaptive capacity. This type of collaboration does not exist in the current forest management system.

### **6.2.2 Provincial forest management**

- **Wildfire management and community wildfire protection** – Recent high impact fire seasons have prompted changes in wildfire management practices and resources, and implementation of community wildfire protection. However, West Kootenay practitioners continue to identify these changes-to-date to be inadequate given projected climate impacts.
- **Climate-sensitive silviculture prescriptions** – Inflexible regulations, tension in the implementation of professional reliance, unfamiliarity with writing rationales including climate change adaptation and the short-term focus on removing free-growing liabilities are barriers to creating climate-sensitive silviculture prescriptions. In the West Kootenays, initially these processes should focus on the highly vulnerable valley-bottom/ mid-elevation landscapes where forests could be significantly altered in the near term.
- **Monitoring** – This project identified that “information management” systems are inadequate, particularly in relation to general monitoring for climate change impacts, and in relation to forest conditions post free-growing. These gaps are particularly of concern given the projected increase in pest and disease impacts.

While some solutions may be found at the regional level, provincial resources are needed to fully address this gap.

- **Climate-sensitive land management plans** – Current land management directions contained in the KBLUP and other legislated direction do not account for climate change, raising concerns about the adequacy of protected areas, connectivity, biodiversity and riparian management practices. Some of these values may be left at significant risk, and an assessment of the risks to landscape values from climate change is needed to identify potential challenges and appropriate adaptation actions moving forward.

### **6.2.3 Public views**

- **Verifying support for adaptation** – Practitioners identified public support and pressure for adaptation in local forest management as a strength. This was echoed in the South Selkirk survey. However, when the **needed adaptations are fully understood, (e.g. priority harvesting of some types of vulnerable forests, extended backcountry closures during high fire hazards)** the public generally, and those directly affected by these adaptations may not be so supportive. Involvement of the public in the next steps in the process will be essential to ensure their views are incorporated, and trust is built in the discussions and decisions about ‘what to do’.

### **6.2.4 Probing the social aspects of forest management adaptation in BC**

- **Expand research and knowledge transfer on social dimensions of adaptation** – To date, research on climate change adaptation in BC forest management has largely focused on the bio-physical impacts and vulnerabilities, with less emphasis on the social aspects. As adaptation is essentially a human activity, and must be supported across the many organizations and diverse interests in BC’s forests to be swiftly implemented, fully understanding the social and psychological barriers to adaptation, and ways to overcome these barriers is crucial, and deserves more attention moving forward. However, the effort and resources required to undertake this type of work should not be under-estimated.

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## **7.0 COLLABORATIVE LEARNING**

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A key element of the project was to engage with local West Kootenay forest management practitioners - broadly defined – with the intention of jointly working through the theories and practices associated with learning about the largely novel information around climate change.

Report #10 (Pinnell 2012) describes the project methodology developed for the survey, workshops, and public outreach component. In particular, it describes how the client group (i.e. science experts and forestry practitioners) was selected, climate change-related information was conveyed to this client group and, in turn, their subsequent input was considered and integrated into the overall project. Through this collaborative effort by the project team and participating client group the new knowledge gained in this project is a result of combined regional knowledge.

In developing the strategies to engage stakeholders in the process, four principles were followed:

1. Local context - information was downscaled and adapted to make it directly applicable to the study area.
2. Local participation – all members of the practitioner client group were engaged in local land or forest management in some capacity.
3. Practical information - information presented was relevant to the participants in that at least some of it could readily be applied into plans and operations.

4. Inspiring change – information and format were developed to provide a foundation from which participants were able to continue advancing knowledge and developing practices to reduce vulnerability of West Kootenay ecosystems with respect to climate change.

A participant survey was conducted followed by a series of workshops to engage forest and land managers in the topic of climate change. As mentioned previously, the survey was used to assess the current state of knowledge and attitudes toward climate change and to guide workshop content. A total of five workshops were held; two were attended by science experts and three were targeted toward practitioners. Each of the science workshops were held in advance of each of the first two practitioner workshops, to peer-review the proposed content and approach to conveying key messages to the forest and land managers and illicit their input. The practitioner workshops were designed to combine general information with small workgroup sessions; in the latter new information was applied in practical scenarios, to inspire conversation and learning. Although the fifth and final workshop was initially intended for the practitioner group only, the science experts were added to this workshop to increase diversity in experience and outlook and because both groups often work together in forest and land management.

In total, approximately 180 stakeholders were selected to participate in the survey. Of the 100 survey recipients who responded, 47 worked in forestry-related fields, 21 were municipal government officials, and 32 were classified as 'other'. The four topic areas within the survey were: (1) climate and the West Kootenays, (2) resilience, (3) adapting to climate change in the future, and (4) background (personal) information. Detailed results from the survey are provided in Report # 10 (Pinnell 2012).

Ten technical experts were selected to be part of the science expert group. The goal was to have 30 attendees at each of the practitioner workshops. The intention was to engage with a broad range of science experts and practitioners in order to ensure a corresponding range of ideas was included in the various analyses.

Due to the detailed nature of the information about the workshops we do not condense the process we took in this document (see Report #10).

In the original planning for the project, we intended to base our structure of engagement on the methods outlined in the Resilience Alliance workbooks ([www.resiliencealliance.org](http://www.resiliencealliance.org)). As our process developed we decided that the existing format of the RA workbooks did not allow us to systematically move through them in the time we had available in this project – instead we took a series of key ideas presented in the workbooks and restructured them into the format of our own process. We ultimately used the Vulnerability Assessment framework for our approach, but based much of our engagement and analysis on elements of the Resilience Alliance approach.

Even after we changed focus to a more structured approach, the project team found the workshops themselves to represent a considerable level of effort – over and above that originally expected. This is a result of a number of factors, including the depth and complexity of the challenge itself (climate change and forest management), and our attempt to embrace the 'integration and participation' aspects suggested by the RA. We believe we all jointly gained valuable experience as a result of this process, and though a time consuming experience, as expressed by the attendees, we also note that the workshops were widely regarded as being positive by the attendees and participants in the process.

Some key results – based on feedback through the survey, and from evaluations from workshop participants include:

### **Information Quality:**

- Local focus (versus provincial or larger scale) made the information relevant to participants and was very important for capturing and maintaining interest throughout the workshop series. Because of the local context, many participants felt they now had enough information to begin to incorporate climate change

considerations into forest management plans and operations. Many of the practitioners were sufficiently motivated by the workshop content to attend all three workshops.

- The scope of information was useful to all groups of participants (i.e., managers, educators, scientists, government – municipal, provincial, federal), and can be applied in the various fields.
- Having the reports and presentations available online for future reference was appreciated. Having a website that targets local climate change related information is useful.
- The information generated by the project has more local credibility because it was created through cooperation between the project team, science experts, and practitioners (most of whom were local).

## **Workshop Format**

- The mixed backgrounds of participants made the workshops very informative. It was useful for science-based people to hear the licensee perspective/viewpoints and vice versa. This process takes significant time however.
- Diversity of participants gave credibility to the process and will help participants achieve success when applying new this information.
- Having short presentations interspersed with group discussions where new information was applied in exercises was effective at engaging the range of attendees.

In addition, a broad community-based follow-up survey, undertaken with our sample of forest practitioners as a subset (Harshaw 2012), concluded:

- There is high interest in local climate change and its potential impacts is supported by survey results reported by Harshaw (2012) where 67% of respondents (primarily located in the West Kootenays) expressed they had some concern about climate change impacts. Most respondents felt their lives were already affected by climate change. Observations included summer drought, warmer winters, mountain pine beetle, melting glaciers and changes to bird migration patterns. Looking into the future, respondents are most concerned about severe insect outbreaks. Other concerns include more frequent extreme weather events, changes in plant and animal distributions and habitats, drought and a reduced timber harvesting landbase. They also believe that forest managers should be doing something in response to climate change.

## **Key messages**

At the end of the final workshop participants were also asked to describe some of the important messages they received. The most common responses were:

- They could see the urgency to act after seeing the climate change modeling results;
- There is some comfort knowing that a local group is engaged in this work looking for local solutions;
- The opportunity to gather and share ideas with other people who are thinking about climate change impacts was valuable;
- The worksheets developed for the workshops are a good resource;
- Being introduced to the concept of structured decision-making was useful as it provides a framework to begin organizing thought processes on such a complex topic; and,
- Participants felt the workshops inspired change and there was commitment to move ahead on this topic.

## **8.0 LESSONS LEARNED AND RECOMMENDATIONS**

This project involved a variety of different issues and approaches. The project team has therefore generated a wide variety of results and key lessons learned. The previous sections of this summary report draw out the key elements of these, however, for ease of reading and compilation, we also produced a final report (Report #11, Holt et al. 2012) which presents in bullet form the key lessons learned from different aspects of the project.

## **9.0 NEXT STEPS**

This project provides a foundation upon which climate change awareness and adaptation in the West Kootenays can be built. General knowledge about climate change is becoming increasingly enmeshed into the consciousness of broader society, and the rate at which this is occurring appears to have increased quite dramatically, even over the short two-year time window of this work. However, by their nature, all the participants in this project could be considered relatively ‘early adopters’ – this includes the working team, the clients, and general participants. Given the relatively new nature of this work, this project should be considered as a first step – upon which additional work should be built.

General objectives moving forward should include the following:

- continue the general momentum for climate change learning and adaptation created by the FFESC project;
- “close the loop” and report the completed project results to the project participants;
- further develop a methodology to aid in determining priorities for action, based on the ecosystem vulnerability assessment, and combined with additional considerations;
- develop site-specific local adaptation recommendations that link to promoting resilience in local forests;
- support interested organizations to identify and implement adaptation actions; and,
- disseminate the information generated during this project to a wider audience. Broad societal understanding and buy-in of the future risks and issues will be key to moving forward more broadly on implementing adaptation actions.

In practical terms this could include the following:

**Moving on from the Early Adopters:** A key next step is to extend and diversify the range of people aware of, and engaged in, climate change forest management issues in the West Kootenays. This can occur at a variety of levels. For example, widening the number and diversity of forest practitioners directly aware of this work. In addition, the working team has taken various opportunities to present the basic results of this work on climate scenarios and bioclimate futures to a wide variety of local audiences. Focusing attention only on those directly involved in forest management is likely to be relatively ineffective in the long-term since external interest and understanding will likely be needed to encourage action by those not in the ‘early adopters’ category. In addition, building public understanding of the risks and vulnerabilities associated with climate change in the West Kootenays, and more broadly, will be an essential element of successful implementation of adaptation strategies.

**From Ecosystems to Values:** In this project we focused primarily on the vulnerability of ecosystems as the unit of consideration. Implications can be drawn from the work on ecosystems and extended, in a general way, to individual values – for example, both timber supply and habitat for many species will likely be impacted by the range of potential futures presented here. A next step therefore is to quantify these implications in a more precise way. This should include exploration into the following: a) identifying relevant sensitivities that should be included within timber supply review, b) identifying key habitat types at risk and determining whether these values can be maintained or restored, and identify appropriate adaptation actions required, c) identifying key areas of human

hazard - particularly with respect to fire management. These three examples are the most obvious, however the list of values affected by the range of potential futures is long and requires focused effort to start to understand the implications – both from a social choice perspective and from a management direction perspective.

**Delving further into potential climate futures:** We present results from three climate scenarios in this project. We have generated local information on future climate, bioclimate envelope shifts and potential implications for fire and insects and disease. It cannot be overstated that the results presented are just a few of the many potential futures, and within this project we only scratched the surface in terms of interpreting the significance of some of these results. Moving forward, further work could be done to delve further into the range of scenarios presented here, and to extend the potential range of climate scenarios more broadly. This work would be important to create a fully rounded set of adaptation options.

**Understanding resilience:** Conceptually, resilience is an intriguing concept that has engaged this project team fairly significantly. On one hand, we found that its application to real situations was difficult – issues were caused by difficult concepts and varied applications in the literature, and by a lack of predictive power to identify potential thresholds and feedback loops. Alternatively, within the project, we did have some success applying resilience concepts in interpreting the vulnerability assessment. Continuing to explore what thresholds may exist, at multiple scales, for ecosystems (and social systems – something we did not engage in here) should continue to be an area of exploration since abrupt, non-linear and potentially catastrophic changes will likely to be an increasingly significant factor in systems dynamics.

**Managing for Resilience:** Moving forward, a meshing of the work done here with general theories on how to promote resilience within forest management would help provide some more specific adaptation options relevant to forest practitioners. Additional factors to consider include moving from ecosystem vulnerabilities to broader societal risks (to a range of values) and also identifying which factors we are capable of changing, and which we must simply adapt to.

**Addressing barriers and opportunities for change:** A wide variety of barriers and opportunities for change are identified in this project. Some of them require further development in relation to specific climate scenarios (e.g. development of ecosystem/ climate appropriate stocking standards). Options developed locally (rather than provincially) may be key to their success.

**A champion moving forward:** We received consistent positive feedback from participants in this project. Among the group of participants there was a high level of frustration about the lack of focused knowledge (rather than ‘fire hose’ information), leadership, conversations and actions relating to climate change both provincially and locally. This project was seen as a welcome and useful starting place. Identifying a champion and appropriate funding to continue this work locally will be key to ensuring that maximum value is extracted from the work to date, and that effective strategies are identified moving forward.

In order to capitalize on the foundation built here the following next steps should be considered:

#### Phase 1 (6 months)

- Workshop with project participants to report and review completed project results.
- Prepare information summaries based on direction from project participants.
- Meet with industry and government managers to report on project results.
- Develop a local working group to mesh results from this work with identifying strategies to manage for resilience into the future.
- Identify priority adaptation factors for further research and potential funding sources.
- Investigate opportunities to increase the number and diversity of forest management practitioners who are familiar with the work generated during this project.

- Investigate opportunities to present results of this project to a broader local and provincial audience.

**Phase 2 (1 year plus)**

- Apply for funding for further research on the variety of issues raised in this project.
- Assess and test decision approaches with local forest practitioners and managers.
- Pilot decision approaches with two organizations to identify and implement adaptation actions.

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## **10.0 REFERENCES**

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- Abbott, C.L., K.E. Bennett, K. Campbell, T.Q. Murdock and H. Swain. 2007. Forest Pests and Climate Change Symposium: 14-15 October 2007, Summary Report. Pacific Climate Impacts Consortium, University of Victoria, Victoria BC, 14 pp. Available at: <http://pacificclimate.org/sites/default/files/publications/Abbott.ForestPestSymposium.Oct2007.pdf>
- Burton, P. 2010. Striving for sustainability and resilience in the face of unprecedented change: the case of the mountain pine beetle outbreak in British Columbia. *Sustainability* 2: 2403 – 2423.
- Chapin, F. S. III, G. Kofinas and C. Folke, eds. 2009. *Principles of Ecosystem Stewardship: Resilience-based resource management in a changing world*. Springer. N.Y.
- Diniz-Filho, J.A.F., Bini, L.M., Rangel, T.F., Loyola, R.D., Hof, C., Nogues-Bravo, D. & Araujo, M.B. 2009. Partitioning and mapping uncertainties in ensembles of forecasts of species turnover under climate change. *Ecography*, 32:897–906.
- Folke, C., S.R. Carpenter, B.H. Walker, M. Scheffer, T. Elmqvist. 2004. Regime shifts, resilience and biodiversity in ecosystem management. *Annual Review in Ecology Evolution and Systematics* 35:557–581.
- Fussel, H.M and R.J.T. Klein. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change*: 75: 301-329.
- Harshaw, H. 2012. South Selkirks forest management and climate change public opinion survey, 2012. Vancouver, BC. UBC Faculty of Forestry. 140pp.
- Holt, R.F., G. Utzig, H. Pinnell and C. Pearce. 2012. Vulnerability, Resilience and Climate Change: Adaptation Potential for Ecosystems and Their Management in the West Kootenay. Report #1 for the West Kootenay Climate Vulnerability and Resilience Project. Available at [www.kootenayresilience.org](http://www.kootenayresilience.org)
- Holt, R.F., G. Utzig and C. Pearce. 2012. Assessment and Decision-making for climate change: an overview of four approaches.. Report #2 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)
- Holt, R.F., G. Utzig, C. Pearce and H. Pinnell. 2012. West Kootenay Climate Vulnerability and Resilience: Lessons Learned. Report # 11 of the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)
- Intergovernmental Panel on Climate Change. 2007. *Climate Change 2007: Synthesis Report*. This report, adopted section by section at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report. 73pp.
- IPCC. 2000. Special report on emissions scenarios (SRES). N. Nakicenovic et al., editors. Special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. Available at: <http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf>

## *Report #1: Summary*

IPCC. 2012. Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

Johnston, M. and Williamson, T. 2007. A framework for assessing climate change vulnerability of the Canadian forest sector. *The Forestry Chronicle* 83: 358-361.

Johnston, M., M. Campagna, P. Gray, H. Kope, J. Loo, A. Ogden, G.A. O'Neill, D. Price and T. Williamson. 2009. Vulnerability of Canada's Tree Species to Climate Change and Management Options for Adaptation: An Overview for Policy Makers and Practitioners. Canadian Council of Forest Ministers, Ottawa, ON.

Klausmeyer, Kirk R., M. Rebecca Shaw, Jason B. MacKenzie, and D. Richard Cameron. 2011. Landscape-scale indicators of biodiversity's vulnerability to climate change. *Ecosphere* 2:art88.[doi:<http://dx.doi.org/10.1890/ES11-00044.1>]

Kliejunas, J.T. 2011. A risk assessment of climate change and the impact of forest diseases on forest ecosystems in the Western United States and Canada. Gen. Tech. Rep. PNW-GTR-236. Albany, CA. USDA, For. Serv., Pacific Southwest Research Station. 70pp.

Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, and M.M. Elsner. 2009. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Chapter 7 in: Littell, J.S., M.M. Elsner, L.C. Whitely Binder, and A.K. Snover (eds). *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate*. Climate Impacts Group, University of Washington. Seattle, WA. Available online at: <http://cses.washington.edu/cig/outreach/waccia/>.

Logan, J.A., J. Régnière, and J. A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. *Front Ecol Environ* 2003; 1(3): 130–137.

Mbogga, M. S., X. Wang, and A. Hamann. 2010. Bioclimate envelope modeling for natural resource management: dealing with uncertainty. *Journal of Applied Ecology* 47:731–740.

Ministry of Forests and Range. 2008. Adapting to climate change: Future Forest Ecosystem Initiative 2007/08 –2009/10 strategic plan. Available at: [http://www.for.gov.bc.ca/ftp/hts/external/publish/web/ffei/project/FFEI\\_Strategic\\_Plan.pdf](http://www.for.gov.bc.ca/ftp/hts/external/publish/web/ffei/project/FFEI_Strategic_Plan.pdf)

Murdock, T. 2010. Past and future climate in Castlegar for stormwater engineering – PIEVC Workshop. Unpubl. Powerpoint Presentation. Pacific Climate Impacts Consortium. Victoria, BC. 48pp.

Murdock, T.Q. and A.T. Werner, 2011. Canadian Columbia Basin Climate Trends and Projections: 2007-2010 Update. Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC, 43 pp. Available at: <http://pacificclimate.org/sites/default/files/publications/Murdock.CBT2007-2010Update.Jul2011.pdf>

Murdock, T.Q. and D.L. Spittlehouse, 2011: Selecting and Using Climate Change Scenarios for British Columbia. Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC, 39 pp.

Parmesan, C. 2006. Ecological and Evolutionary responses to recent climate change. *Ann. Rev. Ecol. Evol. And Syst.* 37(637-669).

Pearce, C. 2012. Achieving Climate Change Adaptation in West Kootenay Forest Management – Barriers, Incentives & Opportunities. Report #6 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

Pearson, R.G., Thuiller, W., Araujo, M.B., Martinez-Meyer, E., Brotons, L., McClean, C., Miles, L., Segurado, P., Dawson, T.P. & Lees, D.C. 2006. Model-based uncertainty in species range prediction. *Journal of Biogeography*, 33:1704–1711

Pinnell, H. 2012. Forest Health and Climate Change: Potential Changes in the West Kootenays. Report #6 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

Pinnell, H. 2012. Project consultations and outreach. Report #10 of the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

## *Report #1: Summary*

- Pinnell, H., R.F. Holt, C. Pearce and and G. Utzig. 2012. Moving Towards Adaptation Strategies in Forest Management – A Starting Place for the West Kootenays. Report #9 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)
- Podur, J.J. and B.M. Wootton. 2010. Will climate change overwhelm fire management capacity? Ecological Modeling 221:1301-1309.
- Raffa K.F., B.H. Aukema, B.J. Bentz, A.L. Carroll, J.A. Hicke, M.G. Turner, W.H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions. Bioscience 58(6): 501-517.
- Scheffer M, Carpenter SR. 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. Trends Ecol Evol 18:648–56.
- Spittlehouse, D. 2008. Climate change, Impacts and Adaptation Scenarios: Climate Change and forest and range management in British Columbia. BC Ministry of Forests and Range, Victoria, British Columbia. Technical Report 45.
- Spittlehouse, D. L. 2006. ClimateBC: Your access to interpolated climate data for BC. Streamline Watershed Management. Bull. 9:16-21.
- Taylor SW, Thandi G (2003) Development and Analysis of a Provincial Natural Disturbance Database. Pacific Forestry Centre, Natural Resources Canada, Victoria, BC, Canada.
- Utzig, G. 2011. Climate Change Projections for the West Kootenays. Report #3 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)
- Utzig, G. 2012. Ecosystem and Tree Species Bioclimate Envelope Modeling for the West Kootenays. Report #5 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org).
- Utzig, G. and R.F. Holt. 2012. An ecosystem vulnerability and resilience assessment for West Kootenay Ecosystems. Report # 7 from the West Kootenay Climate Vulnerability and Resilience Project. Available at [www.kootenayresilience.org](http://www.kootenayresilience.org)
- Utzig, G., J. Boulanger and R.F Holt. 2012. Climate Change and Area Burned: Projections for the West Kootenays. Report #4 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)
- Walker, B., C.S. Holling, S.R. Carpenter and A. Kinzig. 2004. Resilience, adaptability and transformability in social-ecological systems. Ecology and Society 9(2): 5. [online] URL: <http://www.ecologyandsociety.org/vol9/iss2/art5/>
- Walker, B. 2005. A resilience approach to integrated assesments. The Integrated Assessment Journal. Vol 5 (1): 77-97.
- Walker, B. and J.A. Meyers. 2004. Thresholds in ecological and social-ecological systems: a developing database. Ecology and Society online: URL: <http://www.ecologyandsociety.org/vol9/iss2/art3>
- Woods, A.J., D. Heppner, H. Kope, J. Burleigh, and L. MacLaughlan. 2010. Forest health and climate change: a British Columbia perspective. For. Chron., 86:412–422.
- Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313:940–943.

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## **APPENDIX 1: LIST OF REPORTS FROM THIS PROJECT**

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### **Report 1: Overview**

Holt, R.F., G. Utzig, H. Pinnell and C. Pearce. 2012. Vulnerability, Resilience and Climate Change: Adaptation Potential for Ecosystems and Their Management in the West Kootenay – Summary. Report #1 from the West Kootenay Climate Vulnerability and Resilience Project. Available at [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 2: Approach**

Holt, R.F., G. Utzig and C. Pearce. 2012. Assessment and Decision-making for climate change: an overview of four approaches. . Report #2 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 3: Climate Change**

Utzig, G. 2012a. Climate Change Projections for the West Kootenays. Report #3 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 4: Fire**

Utzig, G., J. Boulanger and R.F. Holt. 2012. Climate Change and Area Burned: Projections for the West Kootenays. Report #4 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 5: Bioclimate Modeling**

Utzig, G. 2012b. Ecosystem and Tree Species Bioclimate Envelope Modeling for the West Kootenays. Unpubl. Report. Report #5 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 6: Forest Health**

Pinnell, H. 2012a. Forest Health and Climate Change: Potential Changes in the West Kootenays. Report #6 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 7: Ecosystem Vulnerability Assessment**

Utzig, G. and R.F. Holt. 2012. An ecosystem vulnerability and resilience assessment for West Kootenay Ecosystems. Report # 7 from the West Kootenay Climate Vulnerability and Resilience Project. Available at [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 8: Barriers and Opportunities**

Pearce, C. 2012. Achieving Climate Change Adaptation in West Kootenay Forest Management – Barriers, Incentives & Opportunities. Report #8 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 9: Potential Adaptation Strategies**

Pinnell, H., R.F. Holt, C. Pearce and G. Utzig. 2012. Moving Towards Adaptation Strategies in Forest Management – A Starting Place for the West Kootenays. Report #9 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 10: Consultation and Outreach**

Pinnell, H. 2012b. Project consultations and outreach. Report #10 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

### **Report 11: Lessons Learned**

Holt, R.F., G. Utzig, C. Pearce and H. Pinnell. 2012. West Kootenay Climate Vulnerability and Resilience: Lessons Learned. Report # 11 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: [www.kootenayresilience.org](http://www.kootenayresilience.org)

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## **APPENDIX 2 GENERALIZED ECOSYSTEMS USED IN BIOCLIMATE PROJECTIONS<sup>12</sup>**

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- **Alpine (Alp)**: alpine tundra (e.g., IMA, CMA)
- **Alpine transition (Atran)**: parkland/ woodland alpine transition (e.g., ESSFdmp, ESSFvcw)
- **Wet ESSF (W ESSF)**: wet Engelmann spruce-subalpine fir forest (e.g., ESSFvc)
- **Dry ESSF (D ESSF)**: dry Engelmann spruce-subalpine fir forest (e.g., ESSFdm)
- **CWH**: coastal western hemlock forest (e.g., CWHmm)
- **Coast transition (Ctran)**: coastal transition cedar-hemlock forest (e.g., CWHds, ICHmc)
- **MSW**: wet montane/ sub-boreal spruce forest (e.g., SBSmc)
- **MSD**: dry montane/ sub-boreal spruce forest (e.g., SBPS, SBSdw, MSdk)
- **Wet ICH (W ICH)**: wet interior cedar-hemlock forest (e.g., ICHvk)
- **Moist ICH (M ICH)**: moist interior cedar-hemlock forest (e.g., ICHmw)
- **Dry ICH (D ICH)**: dry interior cedar-hemlock forest (e.g., ICHdw)
- **Grand Fir (GF)**: grand fir – Douglas-fir forest (e.g., ICHxw)
- **Wet IDF (W IDF)**: wet interior Douglas-fir forest (e.g., IDFww)
- **Dry IDF (D IDF)**: dry interior Douglas-fir forest (e.g., IDFdm)
- **Ponderosa Pine (PP)**: ponderosa pine forest and grassland savanna (e.g., PP)
- **Grassland-Steppe (GS)**: grassland and steppe (e.g., BG)

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<sup>12</sup> The example ecosystem units in parentheses are from the BC Biogeoclimatic Classification system – further information can be found at: <http://www.for.gov.bc.ca/hre/becweb/system/how/index.html>